Arizona
University
Library

Presented by

DR. F. N. GUILD

Cambridge Natural Science Manuals
BIOLOGICAL SERIES.
GENERAL EDITOR:—ARTHUR E. SHIPLEY, M.A.
FELLOW AND TUTOR OF CHRIST'S COLLEGE, CAMBRIDGE.

ELEMENTARY

PALÆONTOLOGY.

London: C. J. CLAY AND SONS,
CAMBRIDGE UNIVERSITY PRESS WAREHOUSE,
AVE MARIA LANE.

AND

H. K. LEWIS,
136, GOWER STREET, W.C.

Leipzig: F. A. BROCKHAUS.
New York: THE MACMILLAN CO.

ELEMENTARY

q6r

PALÆONTOLOGY

INVERTEBRATE

BY

HENRY WOODS, M.A., F.G.S.

DEMONSTRATOR IN PALÆOZOOLOGY IN THE UNIVERSITY OF CAMBRIDGE.

SECOND EDITION.

CAMBRIDGE:
AT THE UNIVERSITY PRESS.
1896

[*All Rights reserved.*]

First Edition 1893
Second Edition 1896

CAMBRIDGE: PRINTED BY J. AND C. F. CLAY,
AT THE UNIVERSITY PRESS.

PREFACE TO SECOND EDITION.

THE general plan of this work is to give, in each group of the Invertebrata, first, an account of its general zoological features with a full description of the hard parts of the animals; secondly, its classification and the characters of the important genera; and thirdly, a description of the present distribution, and the geological range. The account of the geographical distribution is given in the hope of calling attention to the problems connected with the distribution of animals in former periods of the earth's history.

In the present edition some parts of the book have been enlarged, and others modified, in accordance with the researches of recent writers, and as the outcome of further experience gained in teaching the subject since the previous edition was issued. Descriptions of a larger number of genera are given, since it is believed that this will make the book more generally useful, while still retaining its elementary character. The description of each genus is followed by the enumeration of one or more typical species, so as to guide the student in making use of a large collection.

136716

The number of illustrations has been doubled; but as before, they are employed mainly for the purpose of explaining structure and terminology, and will not enable the student to dispense with the use of actual specimens.

The list of palæontological works has been considerably lengthened, and is intended to indicate to the student where he may obtain further information in any branch of the subject, but not to give a complete catalogue of even the more important works. In drawing up the list, works of general interest in each group are first mentioned, and secondly, works dealing with the subject from a systematic stand-point, especially those treating of British fossils.

For much advice and help, my thanks are due to the Editor of the Series—Mr A. E. Shipley.

H. WOODS.

St John's College, Cambridge.
October, 1896.

CONTENTS.

PAGE

List of Illustrations viii

Divisions of the Stratified Rocks xii

Introduction 1

Protozoa 13

Porifera 27

Cœlentera 41

Echinoderma 75

Chætopoda 113

Brachiopoda 115

Polyzoa 142

Mollusca 148

Arthropoda 226

List of Palæontological Works 272

Index 286

LIST OF ILLUSTRATIONS.

FIG.		PAGE
1.	Sections of Foraminifera	16
2.	Foraminifera. *Miliola. Textularia. Lagena. Cristellaria. Nodosaria. Globigerina. Rotalia*	17
3.	*Nummulites*	20
4.	*Eozoön*	23
5.	Radiolaria. *Lithocampe. Trochodiscus. Podocyrtis*	25
6.	Diagram of a Sponge	28
7.	Sponge spicules	32
8.	*Siphonia tulipa*, Upper Greensand	34
9.	*Protospongia fenestrata*, Menevian Beds	36
10.	Morphology of Graptolites. *Monograptus. Didymograptus. Diplograptus*	44
11.	*Tetragraptus headi*, Arenig Rocks	46
12.	*Retiolites geinitzi*, Silurian	47
13.	*Diplograptus* with reproductive sacs	49
14.	Early stages of *Monograptus* and *Diplograptus*	50
15.	*Phyllograptus*, Arenig Rocks	55
16.	Stromatoporoidea. *Actinostroma*	56
17.	Diagrammatic sections of a sea-anemone	58
18.	A, Diagrammatic section of a simple coral. B, Section of *Cyathophyllum murchisoni*, Carboniferous Limestone	60
19.	*Montlivaltia trochoides*, Inferior Oolite	61
20.	*Dendrophyllia nigrescens*, Recent. *Cyathophyllum truncatum*, Wenlock Limestone. *Cladochonus crassus*, Carboniferous Limestone	63
21.	Vertical section of *Cyathophyllum murchisoni*, Carboniferous Limestone	65
22.	*Lithostrotion basaltiforme*, Carboniferous Limestone	66
23.	*Clisiophyllum bipartitum*, Carboniferous Limestone	67

FIG. PAGE

24. *Calceola sandalina*, Devonian 68
25. *Heliolites porosus*, Devonian 71
26. Section of spine of *Echinometra*, and plate of *Cidaris* . 76
27. Section of arm of *Astropecten*. 78
28. Diagram of the water-vascular system of a star-fish . . 79
29. Section of the arm of *Ophioglypha* 82
30. Ventral surface of *Ophiura*. Dorsal surface of *Ophioglypha* . 83
31. A, Diagram of a regular echinoid. B, Apical disc of *Echinus* . 85
32. Types of Apical Disc. *Peltastes*. *Echinocorys*. *Collyrites*. *Palæechinus*. *Echinoconus* 86
33. Compound Ambulacral Plates. *Diadema*. *Cyphosoma* . 87
34. Spine and Plate of *Cidaris* 88
35. Under surface of *Micraster cor-anguinum*, Chalk . . . 89
36. Upper surface of *Micraster cor-bovis*, Chalk 96
37. Anchor and plate of *Synapta*. Wheel of *Chirodota*. . . 99
38. *Cyathocrinus longimanus*, Silurian 102
39. *Actinocrinus triacontadactylus*, Carboniferous . . . 103
40. *Apiocrinus parkinsoni*, Bradford Clay 105
41. A, B, *Glyptosphærites leuchtenbergi*, Ordovician. C, *Echinosphærites*, Ordovician 107
42. *Pentremites godoni*, Carboniferous 110
43. Ambulacral area of *Pentremites* 110
44. Section of *Pentremites sulcatus*, Carboniferous . . . 111
45. *Magellania* [=*Waldheimia*] *flavescens*, Recent. Longitudinal section 116
46. *Terebratula obesa*, Upper Chalk 117
47. *Cyrtia exporrecta*, Wenlock Limestone 118
48. *Magellania* [=*Waldheimia*] *flavescens*, Recent. Interior of valves 120
49. Vertical section of shell of *Magellania* 123
50. Horizontal section of shell of *Terebratula maxillata*, Great Oolite 123
51. *Paterina labradorica*, Lower Cambrian 124
52. *Lingula anatina*, Recent 126
53. *Crania anomala*, Recent 128
54. *Productus giganteus*, Carboniferous 129
55. *Chonetes*, Devonian 130
56. *Orthis striatula*, Devonian 132
57. *Spirifer striatus*, Carboniferous 132
58. *Atrypa reticularis*, Wenlock Limestone 134
59. *Rhynchonella* (*Hemithyris*) *psittacea*, Recent 134

FIG.		PAGE
60.	*Rhynchonella acuminata*, Carboniferous	135
61.	*Pentamerus* (*Conchidium*) *knighti*, Aymestry Limestone	136
62.	*Terebratula* (*Liothyris*) *vitrea*, Recent	136
63.	*Terebratulina caput-serpentis*, Recent	137
64.	*Stringocephalus burtini*, Devonian	138
65.	Structure of Polyzoa	143
66.	A, *Smittia landsborovi*, Recent. B, *Tubulipora fimbria*, Recent	144
67.	*Mya arenaria*, Recent	150
68.	*Cytherea chione*, Recent	153
69.	Types of Lamellibranch hinge. *Nucula. Trigonia. Spondylus. Lucina. Lutraria*	156
70.	Section of prismatic layer of *Pinna*, Recent	158
71.	Section of *Hippurites cornu-vaccinum*, Cretaceous	169
72.	Section of *Triton corrugatus*, Recent	181
73.	*Bellerophon*, Carboniferous	186
74.	*Nerinea trachea*, Great Oolite	190
75.	*Hyolithes*, Cambrian	195
76.	Section of *Sepia officinalis*, Recent	202
77.	Section of shell of *Nautilus*	204
78.	Section of *Actinoceras*	207
79.	Aperture of *Gomphoceras bohemicum*, Silurian	207
80.	Sutures of *Parkinsonia*, Inferior Oolite, and *Ceratites*, Muschelkalk	209
81.	Aptychus of an Ammonite, Oxford Clay	210
82.	*Glyphioceras sphericum*, Carboniferous	212
83.	*Ceratites nodosus*, Muschelkalk	213
84.	*Phylloceras heterophyllum*, Lias	214
85.	Suture of *Phylloceras*	214
86.	*Lytoceras fimbriatum*, Lias	215
87.	*Macroscaphites ivani*, Lower Cretaceous	215
88.	*Ægoceras capricornum*, Lias	216
89.	*Harpoceras serpentinum*, Lias	217
90.	Section of *Belemnites*	221
91.	Restoration of a Belemnite	222
92.	*Estheria minuta*, Trias	230
93.	*Calymene blumenbachi*, Wenlock Limestone	231
94.	*Æglina binodosa*, Arenig Beds	232
95.	Hypostome of *Asaphus tyrannus*, Llandeilo Beds	233
96.	Under surface of *Asaphus megistos*, Ordovician	234
97.	Under surface and limbs of *Triarthrus becki*, Ordovician	236

FIG.		PAGE
98.	*Olenus cataractes*, Lingula Flags	238
99.	*Paradoxides davidis*, Menevian Beds	239
100.	*Asaphus tyrannus*, Llandeilo Beds	242
101.	*Acidaspis prevosti*, Silurian	244
102.	*Beyrichia complicata*, Bala Beds	248
103.	*Lepas australis*, Recent	249
104.	*Hymenocaris vermicauda*, Lingula Flags	251
105.	*Caryocaris wrighti*, Arenig Rocks	252
106.	*Glyphea regleyana*, Oxford Clay	254
107.	*Archæoniscus brodiei*, Purbeck Beds	258
108.	*Limulus polyphemus*, Recent	264
109.	*Hemiaspis limuloides*, Ludlow Beds	265
110.	Dorsal surface of *Pterygotus osiliensis*, Upper Silurian	266
111.	Ventral surface of same	267
112.	Restoration of the ventral surface of *Slimonia*, Silurian	269

For the use of figures 16, 83, 84, 86, 87, 88, 89, and 91 the author is indebted to the Council of the Palæontographical Society.

DIVISIONS OF THE STRATIFIED ROCKS.

Cainozoic or Tertiary.

- **Pleistocene** ...
  - Post-glacial deposits (river-gravels, cave-deposits, etc.)
  - Glacial deposits (Boulder Clay, etc.)
- **Pliocene** .....
  - Forest Bed Series
  - Norwich Crag Series
  - Red Crag
  - Coralline Crag
- **Miocene** (not found in England)
- **Oligocene** .....
  - Hamstead Beds
  - Bembridge Beds
  - Headon Beds
- **Eocene** .....
  - Bagshot Beds, Barton Clay, and Bracklesham Beds
  - London Clay
  - Oldhaven Beds
  - Woolwich and Reading Beds
  - Thanet Sands

Mesozoic or Secondary.

- **Cretaceous** ...
  - Upper...
    - Chalk
    - Gault, Upper Greensand, and Red Chalk
  - Lower...
    - Lower Greensand
    - Wealden Beds
- **Jurassic** .....
  - Upper...
    - Purbeck Beds
    - Portland Beds
    - Kimeridge Clay
    - Corallian Beds
    - Oxford Clay (with Kellaways Rock)
  - Middle..
    - Great Oolite Series
      - Cornbrash
      - Forest Marble
      - Bradford Clay
      - Great Oolite
      - Stonesfield Slate
    - Inferior Oolite Series
      - Fuller's Earth
      - Inferior Oolite
      - Passage beds (sands)
  - Lower...
    - Lias
    - Rhætic Series (often placed in the Trias)

- TRIASSIC
  - Keuper Series
  - Muschelkalk (not found in England)
  - Bunter Series

Palæozoic or Primary.

- PERMIAN
  - Magnesian Limestone Series
  - Sandstones, etc.
- CARBONIFEROUS
  - Upper...
    - Coal Measures
    - Millstone Grit
  - Lower... Carboniferous Limestone Group
- DEVONIAN AND OLD RED SANDSTONE
  - Upper
  - Middle
  - Lower
- SILURIAN
  - Downtonian Series
    - Downton Sandstone
    - Upper Ludlow Beds
    - Aymestry Limestone
    - Leintwardine Flags
  - Salopian Series
    - Lower Ludlow Beds
    - Wenlock Limestone
    - Wenlock Shale
    - Woolhope Beds
  - Valentian Series
    - Tarannon Shales
    - Llandovery Beds
- ORDOVICIAN
  - Bala or Caradoc Series
  - Llandeilo Series
  - Arenig Series
- CAMBRIAN
  - Upper...
    - Tremadoc Slates
    - Lingula Flags
  - Middle..
    - Menevian Beds
    - Solva Beds (upper part of Harlech Beds)
  - Lower... *Olenellus* Beds

INTRODUCTION.

From the earliest times it has been known that bodies resembling marine animals occur embedded in the rocks. For several centuries two distinct views were held respecting their nature. By some persons they were thought to have once formed parts of living animals, and consequently to indicate that the spot where they are now found was in past ages covered by the sea. Others, feeling it difficult to account for so much geographical change as would be necessitated by this view, considered that they were not of organic origin at all, but had been formed by some 'plastic force' within the earth—that they were in fact 'Sports of Nature.' But since these bodies resemble in every essential respect the hard parts of animals now existing, we may at once reject this hypothesis.

The remains of animals and plants thus preserved in the rocks are known as fossils, and the study of them forms the subject of Palæontology.

In order that an animal or plant may become a fossil, two conditions are generally necessary: First, it must possess a skeleton of some kind or other, since the

soft parts are rapidly decomposed; consequently such animals as jelly-fishes leave no trace of their existence, unless it be merely an imprint. Secondly, the organism must be covered up by some deposit, otherwise it will soon crumble to dust. Now, since there are comparatively few places on land where material is being deposited to any great extent, it follows that terrestrial animals will stand but little chance of being preserved; the greater number after death will remain on the surface and will in a short time be entirely decomposed. A few may become entombed in peat-bogs, in the dust and ashes thrown out by volcanoes, in the sand of sand-dunes, or by a land-slip; some may be sealed up in deposits of carbonate of lime, such as the travertine thrown down by calcareous springs, or the stalagmite formed on the floor of caves; and lastly, others may be transported by running water and ultimately buried in the bed of a river, of a lake, or of the sea. Such instances, however, are of comparatively rare occurrence. In the case of aquatic animals the conditions for fossilisation are much more favourable, since deposition is more universal in water than on land. Of such aqueous deposits, those formed in the sea will enclose by far the larger number of animals on account of the greater area which these deposits cover.

The structure and composition of the hard parts vary considerably in different groups of animals and plants, some are therefore much more readily preserved as fossils than others. Thus in *Argonauta*, the skeleton consists of a thin shell which is easily broken up; then again in some sponges it is formed of needles of silica, which are held together by the soft parts only and consequently easily become scattered after the death of the animal. But in other cases, as in most of the mollusks and corals,

the skeleton is very strong and not easily destroyed, hence these occur abundantly in the fossil form. Perhaps even more important than the structure, is the composition of the hard parts, which, in the case of insects and some hydrozoans consist of a horny substance known as chitin; in diatoms, in most radiolarians, and in many sponges, of silica; in the bones of vertebrates, chiefly of phosphate of lime; in corals, echinoderms, mollusks and many other animals and some plants, of carbonate of lime; in most plants, of woody or corky tissue: a larger or smaller amount of organic matter is always combined with the mineral. Of these substances, chitin is with difficulty dissolved. Silica in its ordinary crystalline condition is one of the most stable of minerals, but when secreted by an animal or plant it is glassy and isotropic, and is dissolved with comparative ease, so that such skeletons may be entirely removed by the action of percolating water. In organisms with calcareous skeletons the carbonate of lime is easily dissolved by water containing carbonic acid, but the degree of solubility varies according to the condition in which the carbonate of lime is present. In some animals it occurs as aragonite, in others as calcite. Of these two minerals, aragonite is the harder and heavier, its specific gravity being 2·93, whilst that of calcite is only 2·72; aragonite crystallises in the rhombic system, calcite in the hexagonal. Fossil calcite shells (*e.g. Pecten opercularis*) are translucent, their surface is compact, but their interior porous; on the other hand the aragonite shells (*e.g. Pectunculus glycimeris*) are opaque, and have a chalky appearance but a compact structure throughout. If a shell of each kind be suspended in water containing carbonic acid, it will be found that the one composed of aragonite will lose, in the same time, a much greater proportion of

its weight than the other. Further, the calcite shell remains firm longer than the aragonite, the latter being soon reduced to the consistency of kaolin or china-clay. This difference, however, does not appear to be due directly to mineral composition, for Cornish and Kendall found that when crystals of calcite and aragonite were powdered and placed in carbonic acid solutions of the same strength, the aragonite was *not* acted on more rapidly than the calcite, and the same result was obtained with powdered fossil shells. From all these considerations, it is not surprising to find that in some strata the aragonite skeletons have entirely disappeared, whereas those formed of calcite remain. This will obviously be most likely to occur in pervious beds through which a current of water containing carbonic acid flows. A striking instance of the difference in the solubility of calcite and aragonite was furnished by some specimens of the common edible mussel, *Mytilus edulis*, in which the inner layer of the shell is formed of aragonite and the outer of calcite; Dr Sorby found specimens from the raised beach at Hope's Nose, Torquay, which had lost the inner layer but not the outer. In some cases aragonite is replaced by calcite, but then the organic structure is entirely destroyed, and we get merely a mass of calcite crystals. Calcite is never replaced by aragonite.

The mineral character of the skeleton of the chief calcareous organisms is as follows:—

Foraminifera.—The vitreous forms consist of calcite, the porcellanous probably of aragonite.

Actinozoa.—The Alcyonaria are mainly of calcite, but most of the Madreporaria of aragonite.

Echinoderma.—All of calcite.

Polyzoa.—Calcite and aragonite in layers, or, sometimes perhaps, mixed.

Brachiopoda.—All of calcite.

Lamellibranchia.—Many consist entirely of aragonite, but *Ostrea* and *Pecten* of calcite. In *Pinna, Mytilus* and *Spondylus*, the inner layer is of aragonite, the outer of calcite.

Gasteropoda.—The majority are formed of aragonite, but *Scalaria* and some species of *Fusus* are of calcite. In some (*e.g. Patella, Littorina*) the outer layer is calcite.

Cephalopoda.—*Nautilus* and *Sepia* are mainly aragonite, as also were probably the Ammonites. The guard of *Belemnites* is calcite.

Crustacea.—The shell consists of calcite, with some phosphate of lime. In some cases there is a large amount of organic matter.

The condition in which fossils occur depends, as we have seen, on their original composition and on the material in which they are embedded. The chief types are the following:—

1. *The entire organism preserved.* Occasionally the soft parts of the organism are preserved as well as the skeleton, the whole having suffered very little change. Instances of this are, (*a*) the woolly rhinoceros and mammoth frozen into the mud in Northern Siberia, and (*b*) insects and plants encased in fossil resin, known as amber, found in the Oligocene beds on the Baltic shores of Prussia and in the Pliocene beds of Cromer.

2. *The skeleton preserved almost unchanged.* Sometimes when the skeleton alone is preserved, it remains

almost in its original condition, except that it has lost its organic matter. Thus the shells in the Pliocene beds of England differ from living ones only in being lighter, more porous, and generally colourless. In some instances a certain amount of mineral matter, such as carbonate of lime, has been added to the skeleton, making it heavier and more compact.

3. *Carbonisation.* In some plants, and in animals with chitinous skeletons, such as graptolites, the original material becomes carbonised. The organism undergoes decomposition where there is but little access of air, it loses oxygen, and consequently the percentage of carbon increases.

4. *A mould of the skeleton.* Sometimes the skeleton disappears entirely, a mould only remaining: this is especially the case when it consists of aragonite and is embedded in a porous stratum. After the shell of a mollusk has become covered up with sediment, and the soft parts have been decomposed, the interior becomes filled with the same material. Water containing carbonic acid subsequently percolates through the rock and carries away the shell as bicarbonate of lime, so that there is left only a mould of the interior and of the exterior, the space between the two being that which was originally occupied by the shell and, if filled with wax, will give an exact model of it. Excellent examples of this mode of fossilisation are seen in some mollusks from the Portland Oolite, *e.g. Cerithium* and *Trigonia*. Sometimes after the shell has been removed, the space left becomes filled up with mineral matter carried in by percolating water; this has the form of the original skeleton but obviously not its internal structure.

The interior of the shells of foraminifera or other organisms may, soon after the death of the animal, become filled with glauconite (silicate of iron and alumina), calcite, or silica, subsequently the shell itself often disappears leaving only the internal cast. Glauconite occurs in this way in the various greensand strata, and also in some of the deep-sea deposits at the present day.

5. *Petrifaction.* In some deposits the fossils show the minute structure as well as the form of the organism, but the original material of the skeleton has been replaced by another mineral. Thus we find fossil wood which shows the cells and vessels just as in existing trees, but in which the walls are formed of silica instead of cellulose. The change has gone on in such a manner that as each particle disappeared its place was taken by a particle of silica. The chief minerals which replace the original substance of organisms in this manner are:—

(i) Carbonate of lime; calcite sometimes replaces the silica of sponges, and the aragonite of mollusks.

(ii) Silica, as in the fossils from the Blackdown Greensand, and the Thanet Sands near Faversham; also in the wood of the Purbeck dirt-bed in the Isle of Portland.

(iii) Iron pyrites; *e.g.* Ammonites from the Oxford Clay, Lias, etc., and some graptolites.

(iv) Oxide of iron, in the form of limonite in some fossils from the Dogger (Inferior Oolite) of Yorkshire and the Lower Greensand of Potton etc., and as hæmatite in fossils from the Carboniferous Limestone of Cumberland.

(v) In rare cases there are other replacing minerals, such as sulphate of lime, barytes, blende, galena, malachite, vivianite, and spathic iron.

6. *Imprints.* The footprints of animals are sometimes found in the rocks, and these, although forming no part of the animal itself, are nevertheless regarded as fossils.

In endeavouring to discover the changes which have taken place on the earth in past geological times, the evidence furnished by fossils is of primary importance. Each great group of the stratified rocks, known as a system, is characterised by a particular assemblage of genera and species, some of which are confined to it and enable us to identify the system. In a similar manner, the smaller divisions—the series and stages, are each characterised by possessing certain fossils, which do not occur above or below. Further, it is found that the fauna of the smallest division (stage or group of beds) is not of uniform character throughout; although there may be no change in nature of the rock, some of the species which are abundant at one level will become rare or extinct in passing to higher or lower horizons. Consequently, a set of beds may be divided into belts or zones, the general aspect of the fauna of each zone being somewhat different from that of the others, but between these divisions there will be no break either physical or palæontological. If then we have determined the order of succession of the formations in any one area by means of their relative positions, the newer resting on the older, it is fairly easy in any other district, merely by examining the fossils, to refer any set of beds to its proper position in the

eological record. But although this law of the identi-
cation of strata by the fossils which they contain is of
reat value, it must not be applied without some caution,
or even if two formations were deposited at exactly the
ame time, it does not necessarily follow that all the
enera and species found in the two will be identical.
Thus for instance in the seas at the present day the same
orms of life do not occur in all parts. There is a dis-
ribution in provinces, depending largely on climatic
onditions, each province possessing some forms peculiar
o itself. The organisms now being entombed in deposits
rmed, say, off the British coasts, will as a whole
e different from those off the Canary Islands, but still
ome of the species and many of the genera will be
ommon to both areas, and will enable us to identify
he two deposits as having been formed within the same
eneral period, but not to say that they are absolutely
ynchronous. Then again there is a distribution of
rganisms according to the depth of the sea, and the
ature of the sea-bottom, so that the fauna of a deep-
ater formation will necessarily be different from that of
shallow-water one, and that of a sandstone different
om that of a clay.

In addition to their chronological value, fossils are
so important in indicating the conditions under which
he formations were deposited. In the case of the later
eds, where most of the fossils belong to genera which are
ill existing, it is easy to distinguish a marine deposit
om one formed in freshwater or on land. Even in the
cks of earlier periods, in which most of the genera are
tinct, we may recognise a marine deposit by the presence
such animals as corals, echinoderms, brachiopods, or

cephalopods, which at the present day are found only in the sea.

The depth of the sea in which a formation was deposited can be estimated when the fossils belong to living species; when the species are extinct, some idea may be formed if the genera to which they belong are found chiefly at some particular depth at the present day. In attempting such determinations, it must be remembered that the sea-bottom down to a depth of nearly 50 fathoms may be disturbed by the action of waves and currents in the sea; consequently the animals living on the bottom in shallow water are liable to be carried from their original home to higher or lower levels. One of the safest indications that a formation was laid down in shallow water and not far from land is furnished by the association of the fossil remains of land animals and plants with marine species; another, by the presence of mollusks such as *Pholas* and *Lithodomus*, which bore into rocks, and at the present day are found only in shallow water.

The nature of the climates of past ages may be judged to some extent by the character of the fossils; the evidence furnished by plants is particularly valuable, since their distribution is determined largely by temperature and is better marked than in the case of marine animals. As far as the latter are concerned it is only when we are dealing with modern species that we can, as a rule, speak with any degree of certainty on this subject; this is owing to the fact that at the present day the individual species of the same genus have often a very different distribution, some being found in warm, others in cold regions. Even when all the fossils in a formation belong to extinct species, the assemblage of genera is some

mes such as marks some region at the present day; us, for example, in the London Clay we find that many the genera of mollusks are now characteristic of tropical subtropical seas.

The study of fossil animals and plants is of the ghest importance to the biologist, not only because ey are the ancestors of modern species, but because nong fossil forms we find many groups which are together extinct, and which often throw light on the lationships of existing animals and plants. In some ses the ancient forms serve to connect groups which, at e present day, appear to be quite distinct; thus, for xample, the earliest known bird (*Archæopteryx* from the olenhofen Limestone, Upper Jurassic) shows, in several nportant characters, affinities to the Reptiles; on the her hand the Deinosaurs, a group of reptiles found in e Mesozoic formations, have many features which link em with the Birds. From the point of view of the ologist, the greatest interest in Palæontology is found in e bearing it has on the subject of evolution: it is only a study of the fossil forms that the genealogy of imals and plants can be traced with certainty; but attempting to work out problems of this nature, a eat difficulty is presented by the imperfection of the cord of the life of past ages, only a very small pro- rtion of the animals and plants having been preserved, d these often in a very imperfect manner. We have ready seen several reasons why this record must be nperfect; some animals are without hard parts; others, rticularly land animals, do not become covered up with diment. Further, the remains of animals which were iginally present in some rocks have been dissolved by

percolating water, or to a great extent obliterated b
the metamorphism which the rock has undergone. The
again the record of life is incomplete because of th
breaks in the succession of the stratified rocks; thes
breaks have been caused sometimes by denudation having
removed a great thickness of rocks, in other cases by a
absence of deposition.

I. PROTOZOA.

Classes.	*Orders.*
1. Gymnomyxa (Rhizopoda)	1. Foraminifera. 2. Radiolaria. 3. Others not found fossil.
2. Corticata (not fossil).	

E Protozoa include the lowest forms of animals, such as *mœba*, *Vorticella* and *Globigerina*. The body consists many cases of one cell only, in others of more than e, but the cells never form tissues as they do in all other mals.

In some Protozoa (the *Gymnomyxa*) the protoplasm with the exception of the nucleus, of uniform character oughout; such forms are further characterised by having definite shape, by being able to take in food at any t of the body, and by possessing the power of throwing lobes or filaments of protoplasm known as *pseudopodia*. others (the *Corticata*) the central uniform mass of toplasm is surrounded by a denser outer layer (the ical layer) which gives the animal a definite form; the d is generally taken in at one permanent aperture, and udopodia are absent, but in many cases the surface is vided with *cilia* or *flagella*, which are threads of proto- sm having a definite form and a rhythmic movement.

Reproduction in the Protozoa takes place asexually by

means of fission and by the formation of spores. There are some cases in which conjugation occurs, representing to some extent the sexual method of the higher animals. In some of the Protozoa there is no skeleton, but in others a shell is formed.

The Protozoa can be divided into two main groups (1) the Gymnomyxa or Rhizopoda, (2) the Corticata; no examples of the latter division have been definitely recognised in the fossil state.

CLASS I. GYMNOMYXA.

The members of this group possess no cortical layer and are able to throw out pseudopodia.

The Gymnomyxa are divided into five or more orders but only two of these have been found fossil, namely the Foraminifera (or Reticularia) and the Radiolaria.

ORDER I. FORAMINIFERA.

The Foraminifera are characterized by giving out thread-like pseudopodia, which frequently branch and anastomose; and by possessing in most cases a shell or test, which may be calcareous, arenaceous, siliceous, or chitinous.

The calcareous forms are by far the commonest, and in these, two kinds of test may be distinguished, namely the *vitreous* and the *porcellanous*. In the vitreous, the test is glassy and transparent, and is perforated by innumerable tubes for the passage of the pseudopodia; in some forms (*e.g. Rotalia*) these tubes are $\frac{1}{3000}$ of an inch in diameter, but in others (*e.g. Operculina*) only $\frac{1}{16000}$ of an inch. In the porcellanous forms, the test, when viewed by reflected light, is opaque and white, having the

ppearance of porcelain ; it is not perforated by tubes, the hole of the pseudopodia passing out by one or two large pertures. Sometimes, however, the surface of the shell pitted, producing at first sight the appearance of per-ration.

In the arenaceous forms the shell consists of grains of nd (commonly quartz) joined together by a cement. The ment may be formed of chitinous, or of calcareous and rruginous material. The test is often imperforate.

The chitinous forms do not occur as fossils. In one nus only is the test siliceous.

The shell of the Foraminifera varies considerably in rm; in some genera it consists of a single chamber, hen it is said to be *unilocular*, as for example in *rbulina*, where it is spherical, and in *Lagena* (fig. *F*), where it is generally flask-shaped. In other ses it consists of several chambers, which are placed communication with one another, either by perfora-ons in the walls (septa) between them, or by larger enings. The arrangement of the chambers in these *ultilocular* forms is very varied, they may be placed a straight line as in *Nodosaria* (fig. 2 *H*), in a curved e as in *Dentalina*, in a plane spiral as in *Cristellaria* g. 2 *G*), or in a helicoid spiral as in *Rotalia* (fig. 2 *L*, *M*). he earlier whorls in some spiral forms are partly or tirely embraced by the later ones, so that sometimes e last whorl only is visible (*e.g. Cristellaria*); but when e later chambers are merely attached to the extremities the earlier ones, all the whorls are visible (*e.g. Rotalia*).

In the porcellanous and the simpler vitreous forms e septum between the chambers (fig. 1 *A*, *b*) is formed tirely by the wall of the older chamber, but in the gher vitreous forms each chamber possesses a wall of

its own, so that the septum (fig. 1 *B*, *b*) is formed of two lamellæ. In such cases the outer walls of the chambers are

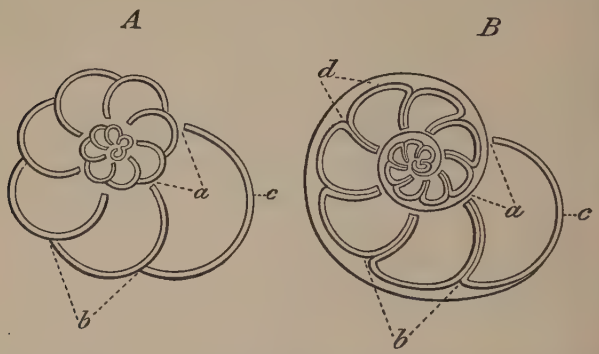
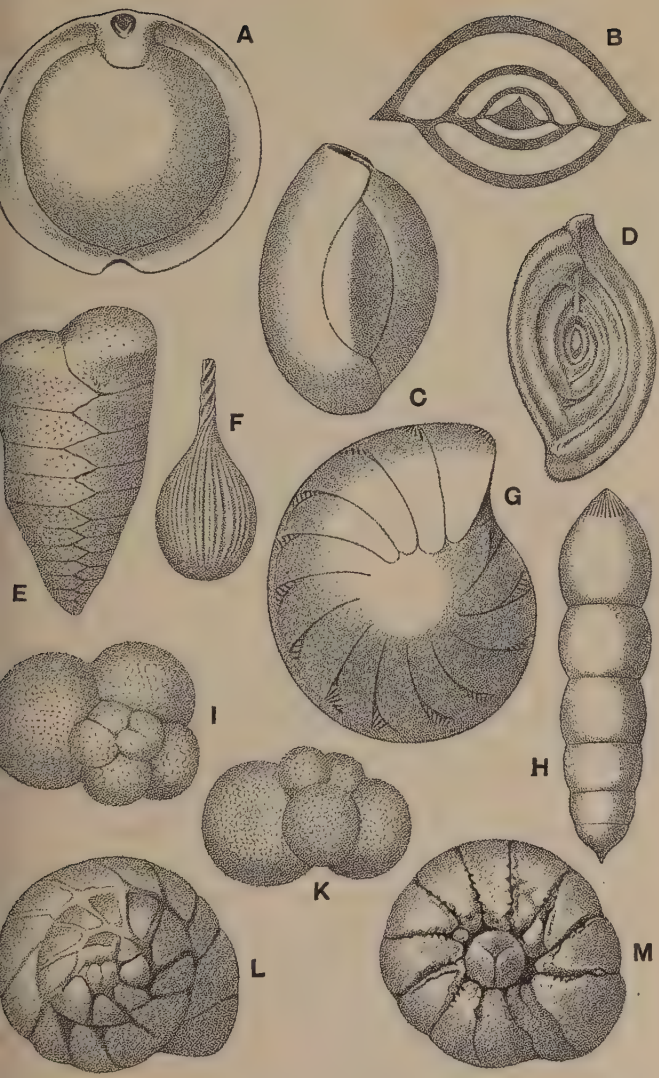


FIG. 1. *A*, section of a foraminifer in which each septum is formed of a single lamella. *B*, in which the septum is formed of two lamellæ. *a*, passages between the chambers; *b*, septum; *c*, anterior wall of last chamber; *d*, supplemental skeleton. (After Carpenter.)

frequently strengthened by a deposit on their surfaces, which fills up the hollows between them; this deposit is often traversed by a system of canals, and is known as the *supplemental skeleton* (fig. 1 *B*, *d*). The Foraminifera may be divided into three groups, the characters of which are based on the structure and composition of the test; this is probably not a natural classification since in some types which are usually calcareous (*e.g. Miliola*) we occasionally meet with species having sandy shells.

I. *Porcellanous Forms.*

Shell calcareous, porcellanous, not perforated by canals, but provided with one or two large apertures through which all the pseudopodia pass out.



. 2. Foraminifera (recent). *A*, *B*, *Miliola* (*Biloculina*) *depressa*. *B*, section. *C*, *Miliola* (*Miliolina*) *seminulum*. *D*, *Miliola* (*Spiroloculina*) *limbata*. *E*, *Textularia barretti*. *F*, *Lagena sulcata*. *G*, *Cristellaria rotulata*. *H*, *Nodosaria radicula*. *I*, *K*, *Globigerina bulloides*. *L*, *M*, *Rotalia beccari*. (After Brady, "Challenger" Report.)

Miliola. (fig. 2, *A—D.*) Test multilocular, the chambers being coiled on an elongated axis, each chamber forming half a convolution. Sometimes all the chambers are visible externally on both sides of the shell (fig. 2, *D*); at other times, owing to the lateral prolongations of the chambers, only the last one or two are seen (fig. 2, *A, C*); or it may be that more chambers are shown on one side than on the other. The external features of the shell consequently vary considerably, and on this account the forms included under the term *Miliola* are now regarded as constituting a number of distinct genera, some of which are mentioned below. Trias to present day. Ex. *Miliolina seminulum,* Eocene to present day; *Biloculina ringens,* Eocene to present day; *Spiroloculina planulata,* London Clay to present day.

II. *Arenaceous Forms.*

Shell composed of grains of sand cemented together by chitinous, calcareous, or ferruginous material.

Saccamina. Test usually free, compact, thick, formed of a single spherical, pyriform, or fusiform chamber with a projecting aperture or of a number of chambers united end to end. Surface smooth or nearly smooth. Ordovician, Carboniferous, and living. Ex. *S. carteri,* Carboniferous Limestone.

Lituola. Shell free, composed of coarse grains, spiral or crosier-shaped. Septa labyrinthine. Aperture simple or sieve-like. Carboniferous to present day. Ex. *L. nautiloidea,* Chalk.

Endothyra. Shell free, spiral (similar to *Rotalia*); chambers numerous, composed of an outer calcareous,

perforated layer, and an inner, compact layer formed of small grains cemented together. Carboniferous and present day. Ex. *E. bowmani*, Carboniferous Limestone.

Textularia. (fig. 2, *E.*) Test arenaceous, (in the small forms it is vitreous); form variable, conical, pyriform, or cuneiform; composed of numerous chambers in two alternating parallel series. Aperture slit-like on the inner edge of the last chamber. Carboniferous to present day. Ex. *T. globulosa*, Chalk.

III. *Vitreous Forms.*

Shell calcareous, vitreous, perforated by numerous minute canals for the passage of the pseudopodia.

Lagena. (fig. 2, *F.*) Test unilocular, very finely perforated. Form globose, ovate or flask-shaped. A single terminal aperture, sometimes at the end of a long neck; rarely two apertures. Surface smooth, ribbed, or spinous. Wenlock Beds to present day. Ex. *L. striata*, London Clay to present day; *L. sulcata*, Silurian to present day.

Nodosaria. (fig. 2, *H.*) Test composed of a number of chambers arranged in a straight line, and separated by constrictions. Aperture at the apex of the last chamber. Surface smooth or ornamented with granules, spines, or ribs. Silurian to present day. Ex. *N. zippei*, Chalk.

Globigerina. (fig. 2, *I*, *K.*) Test perforated by large canals, multilocular; chambers globular, few, arranged in a plane or helicoid spiral, each chamber opening by a large aperture into a central cavity. No supplemental skeleton. Trias to present day. Ex. *G. cretacea*, Chalk.

Rotalia. (fig. 2, *L*, *M*.) Test very finely perforated, multilocular. The chambers arranged in a helicoid spiral, so that on the upper surface all the whorls are seen, on the lower, only the last one. The aperture is in the form of a curved fissure on the lower surface of the last segment. The septa are formed of two layers. A supplemental skeleton is sometimes present. Upper Jurassic to present day. Ex. *R. beccari*, Miocene to present day.

Fusulina. Shell fusiform, composed of elongated whorls; each whorl completely covers the preceding one, and is divided into a number of chambers by septa. Adjoining chambers communicate by a slit at the middle of the base of the septum. Septa folded, each consisting of a single layer. Aperture in the form of a fissure. Carboniferous and Permian. Ex. *F. cylindrica*, Carboniferous Limestone.

Nummulites. (fig. 3.) Test lenticular in form, and composed of a large number of whorls coiled in a plane

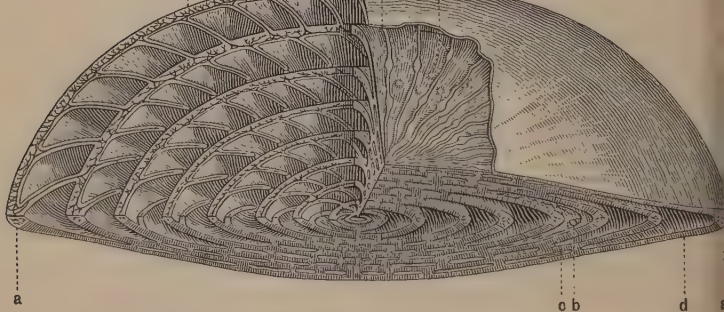


FIG. 3. *Nummulites*, showing vertical and horizontal sections. *a*, marginal cord, with system of canals; *b*, septum, with canals; *c*, chambers; *d*, test; *e*, pillars coming from the supplemental skeleton. (After Zittel.)

spiral. Each whorl completely encloses the preceding one by means of the lateral prolongations of the chambers, so that externally only the last whorl of the shell is visible. The whorls are divided into chambers (*c*) by septa (*b*) which are slightly curved backwards; each chamber communicates with the neighbouring one by means of a median fissure placed next to the margin of the previous whorl. Each septum is formed by two lamellæ. A supplemental skeleton is present, the larger part of it forming what has been termed the 'marginal cord' (*a*). The general shell-substance is minutely perforated, and a system of canals also traverses the septa and supplemental skeleton. Aperture in the form of a slit at the inner margin of the last chamber. The earliest species of *Nummulites* occurs in the Carboniferous Limestone of Belgium; others have been recorded from the Upper Jurassic of Amberg (Bavaria); the genus attains its maximum in the Eocene; only one or two rather rare forms are living, one of which (*N. cummingi*) is found in shallow water in tropical and sub-tropical regions. In the English Eocene the genus is found in the Barton and the Bracklesham Beds. Ex. *N. lævigatus*, Bracklesham Beds.

Distribution of the Foraminifera.

The majority of the Foraminifera are marine, most of them living on the sea-bottom. A few however, as for instance *Globigerina*, exist at or near the surface in the open ocean, and these are very important on account of their abundance. The earliest examples of the Foraminifera are found in the Ordovician rocks, but they are rare until we reach the Carboniferous, some beds of which are formed largely of them, as for instance,

the *Saccamina*-limestone of the north of England and Scotland, the *Endothyra*-limestone of North America, and the *Fusulina*-limestone of Russia, America etc. The order continues to be well represented throughout the Mesozoic formations, particularly in the Chalk, and it attains its greatest development in Tertiary and recent times. In the Eocene the genus *Nummulites* is extremely abundant, forming the massive Nummulitic Limestone of Southern Europe, Egypt, Asia Minor, and the Himalayas.

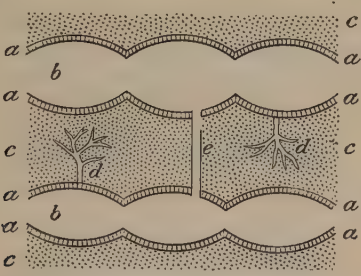
The genera and species of the Foraminifera have generally, as might be expected from their low organization, a long range in time; some of the species which occur in the Palæozoic are still living.

EOZOÖN. In the year 1864 the name *Eozoön canadense* was given by Dawson to a peculiar body found in the Laurentian rocks of Canada, and referred by Carpenter and himself to the Foraminifera. Other 'species' were subsequently found in Bavaria, Bohemia, Silesia and elsewhere.

The Laurentian rocks of Canada consist of two divisions, an upper and a lower. The lower is composed of gneisses and schists, with intercalated beds of crystalline limestone. In the latter, *Eozoön* occurs, frequently in the form of extensive sheets or masses; but according to Dawson, recently collected examples "have established the fact that the normal shape of young and isolated specimens of *Eozoön canadense* is a broadly-turbinate, funnel-shaped or top-shaped form, sometimes with a depression on the upper surface, giving it the appearance of the ordinary cup-shaped Mediterranean sponges." In the limestone of Côte St. Pierre, *Eozoön* occurs as a layer, from two to four inches in thickness, surrounding nodular masses of serpentine or pyroxene.

A hand-specimen of *Eozoön* shows it to consist of alternating layers of a green mineral, serpentine, and a white mineral, calcite. In thin sections viewed under the microscope, the serpentine is seen in some cases to have a fairly regular and more or less beaded form. This layer is considered by Dawson and Carpenter to fill the space which was originally occupied by the soft parts of the animal

fig. 4, *b*), the serpentine having been introduced subsequently by nfiltration, and thus forming a cast of the body chambers. On ach side of the serpentine and between it and the layer of calcite, here may be seen in good specimens a thin lamina (*a*), said to be



IG. 4. Diagram to explain the organic theory of *Eozoön*. *a*, shell-wall; *b*, body-chamber; *c*, supplemental skeleton; *d*, canals in the supplemental skeleton; *e*, stolon-passages.

alcareous and perforated by numerous tubules; this lamina is compared with the shell-wall of the Foraminifera such as *Globigerina*, he tubules being the perforations for the passage of the pseudopodia. External to the lamina is the thick layer of calcite (*c*), which is raversed by numerous branching canals (*d*), and by others (*e*) which ass directly from one chamber to another placing them in communication. These canals are filled with serpentine, or occasionally alcite. This thick layer is regarded as the supplemental skeleton, he branching canals representing the complicated canal-system.

If *Eozoön* be organic, it must certainly be placed among the oraminifera, of which it will be a gigantic example. Several uthors, however, especially King and Rowney in this country, and öbius in Germany, have brought forward weighty objections to is view. They state that the chamber casts of serpentine are, as rule, very irregular in form and cannot be compared with the hambers of the Foraminifera; they consider them to be merely ranules of serpentine in a matrix of calcite; in fact, the structure similar to the banded arrangement seen in some metamorphic ocks. The lamina is shown to be not calcareous but to consist chrysolite, a fibrous variety of serpentine, derived from the alteration of the latter, and in some cases a gradual passage can be

traced from the unaltered serpentine to the fibrous chrysolite. A layer of the same mineral is frequently seen surrounding nodules of serpentine in ophites. The supplemental skeleton is found not to be of uniform structure throughout, but to contain masses of pyrites and other minerals; the branching canals are much too irregular both in form and distribution to be at all comparable to the canal system of a supplemental skeleton, and they are regarded merely as crystals of metaxite. *Eozoön* has never been found in any unaltered rock, and no other fossils have been discovered in association with it. Recently, structures very similar to those exhibited by *Eozoön* have been described by Johnston-Lavis and Gregory in blocks of metamorphosed limestone from Monte Somma.

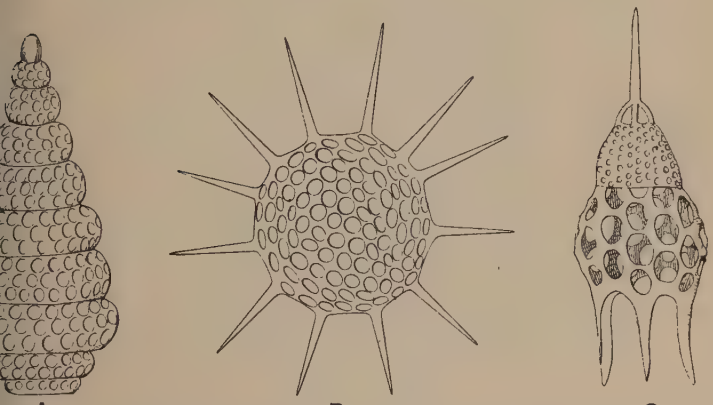
ORDER II. RADIOLARIA.

In the Radiolaria the body consists of a central mass of protoplasm, enclosed in a membrane known as the *central capsule*. The intracapsular protoplasm contains one or more nuclei, and is continuous, through pores in the capsule, with a layer of protoplasm outside the capsule; this layer gives off thread-like pseudopodia, which occasionally unite. A skeleton (fig. 5) is generally developed, composed either of silica, a silicate of carbon, or a peculiar horny substance know as acanthin. The form of the skeleton varies considerably; it may be entirely outside the central capsule or partly within; and consists either of isolated spicules, or of a lattice-like structure frequently with projecting spines.

The Radiolaria do not live in freshwater, but they have a very wide distribution in the sea, being found in all climates and at all depths, and showing the greatest variety of form in tropical regions. In some of the deeper parts of the Pacific and Indian Oceans the shells of these animals, after death, fall and accumulate on the sea-bottom forming a siliceous deposit known as 'radiolarian ooze.'

Cayeux has recently described as Radiolaria some odies found in the Pre-Cambrian rocks of Brittany; they re much smaller than later forms of the group, and are hought by some authors to be simply inorganic aggrega- ions.

In Britain the earliest examples of the Radiolaria occur n the Ordovician rocks of the south of Scotland, where hey form beds of chert; others, which are perhaps of about he same age, have been found in a chert from Mullion sland (off the west coast of the Lizard). A few specimens



IG. 5. Fossil Radiolaria. *A*, *Lithocampe tschernyschewi*, Devonian. *B*, *Trochodiscus longispinus*, Carboniferous. *C*, *Podocyrtis schomburgki*, Barbados Earth (Tertiary). All largely magnified.

ave been noticed in the Carboniferous Limestone of lintshire, whilst in the Lower Culm Measures of Devon nd Cornwall these organisms contribute largely to the rmation of thick beds of siliceous rock (cherts, etc.). At veral localities on the continent Radiolaria are fairly mmon in the Mesozoic formations, but in England only

a few specimens have been recorded from the Lias, the Lower Greensand, the Upper Greensand, the Cambridge Greensand, and the Chalk. In the Tertiary a few have been obtained from the London Clay of Sheppey. A very important Radiolarian formation of late Tertiary age covers large areas in the Island of Barbados, and is known as the 'Barbados earth'; it resembles very closely the modern Radiolarian ooze mentioned above, and is probably a deep-sea deposit.

II. PORIFERA.

Class.	*Orders.*
1. Non-Calcarea.....	1. Myxospongiæ. 2. Ceratospongiæ. 3. Monactinellidæ. 4. Tetractinellidæ. 5. Lithistidæ. 6. Hexactinellidæ. 7. Octactinellidæ. 8. Heteractinellidæ.
2. Calcarea (Calcispongiæ).	

HE Porifera or Sponges are distinguished from the Protozoa by the body being always multicellular, by the cells being arranged in definite layers, and by the occurrence of sexual reproduction.

The body of the sponge is very variable in shape; in its simple form it consists of a sac open at the upper end, and in nearly all cases attached to some foreign object by the lower. In the living state a large number of small openings termed *pores* (fig. 6, *p*) may be seen on the surface; these are the openings of canals leading to the interior, known as the *incurrent canals* (fig. 6, *i*). The incurrent canals often open into globular chambers (*c*), from which the *excurrent canals* (*e*) pass to the central cavity of the sponge, their openings on the inner surface being

the *ostia* (*o*). The opening of the central cavity to the exterior is termed the *osculum* (*os*), in some cases there is only one, which is then placed at the summit of the sponge; in others there are several. A continual current of water flows through the sponge, passing in by the pores and out by the osculum. By means of this the processes of respiration, nutrition and excretion go on.

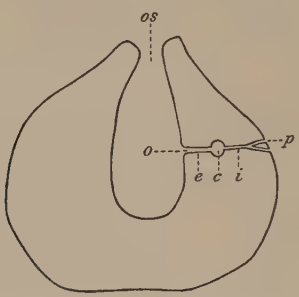


Fig. 6. Diagram of a simple Sponge, one canal only shown. *os*, osculum; *p*, pores; *i*, incurrent or inhalent canal; *c*, globular chamber; *e*, excurrent or exhalent canal; *o*, ostium.

The wall of the sponge is formed of three layers. The outer one is the *ectoderm* and consists of a single layer of flattened cells. The inner is the *endoderm*; it lines the globular chambers and the excurrent canals and is, as a rule, similar to the ectoderm, except in the chambers, where each cell is provided with a collar and a flagellum, the movements of the latter producing the current of water spoken of above. Between the endoderm and the ectoderm is the *mesoderm*, which is much thicker than the other layers and consists of gelatinous material containing cells, some of which give rise to the skeleton.

In nearly all sponges there is a skeleton, which serves to support the soft parts and to prevent the canals from

losing. For systematic purposes its structure is found o be of great importance, since the external form of the ponge varies considerably even in the same species. The keleton may consist of fibres of a horny substance known s *spongin*, or of mineral particles (termed *spicules*) of arious forms (fig. 7), composed of carbonate of lime or f silica, or it may consist of both siliceous spicules and pongin. Those forms only which have either a siliceous r calcareous skeleton are definitely known as fossils. In ome groups the spicules are not united, as for instance in he Monactinellidæ and Tetractinellidæ, but in others they re fused together or interlocked so as to form a complete caffolding, and generally it is in these only that the exernal form of the sponge can be preserved in the fossil tate. In most sponges, two kinds of spicules may be listinguished, the *skeletal-spicules* which build the main art of the skeleton, and the *flesh-spicules* which are maller and isolated and are seldom preserved as fossils. n the centre of each spicule, there is a tube known as the *xial canal* (fig. 7*c*), which in the living animal is occupied y a thread of organic matter. The spicules of recent iliceous sponges are characterised by the glassy appearnce of their surface, and by the silica being colloidal, sotropic, and soluble in heated caustic potash. But in he fossil state the spicules have generally undergone onsiderable change, occasionally their silica is still colloidal but the surface has no longer the glassy appearance, nd the axial canal is frequently filled with silica in a rystalline or crypto-crystalline condition, and is consequently easily distinguished by the aid of polarised light vhen the spicule itself still remains colloidal; generally nowever the spicule has become crystalline or cryptorystalline, and when this is the case the axial canal can

rarely be detected since it is filled with material in the same condition. Sometimes the silica of the spicules has been entirely removed, in some cases a hollow cast only remaining; in others its place is taken by another mineral as for instance by calcite in the sponges from the Lower Chalk of Dover and Folkestone, by iron pyrites in *Protospongia* from the Menevian Beds of St David's, by iron peroxide in the sponges of the Upper Chalk of the south of England, by glauconite in some from the Upper Greensand. Obviously then silica in the colloidal state in which it occurs in recent sponges is anything but a stable substance, thus differing widely from its crystalline and crypto-crystalline condition.

The spicules of the calcareous sponges are usually smaller than those of the siliceous forms, and their material is not in an isotropic state, each one being optically a crystal of calcite but having the form and structure of a spicule; consequently in polarised light they are readily distinguished from the siliceous forms. Then again the fossil calcareous spicules have undergone much less chemical change than the siliceous ones; generally they are still composed of carbonate of lime, it is only in rare cases that this is replaced by silica, but at the same time the external form of the individual calcareous spicules is often less well preserved.

The canal-system is indicated in the skeleton of both recent and fossil forms, by spaces in the spicular framework, but these spaces represent only the larger canals the smaller existing in the soft parts alone.

Reproduction in the sponges takes place by budding or gemmation, and sexually.

Various classifications of the sponges have been proposed by different authors; in the one adopted here the

Order 4. Tetractinellidæ. The spicules (fig. 7, *b*, *c*) are held together by spongin, they consist of four rays given off from a common centre, the angle between each of the rays being 120°. The rays may be equal or unequal in length, frequently one is very much elongated, and sometimes their terminations are bifurcated. Like the Monactinellids, the Tetractinellids are seldom preserved in anything like a perfect condition as fossils. The oldest forms occur in the Carboniferous Limestone, where they are represented by the genera *Geodites* and *Pachastrella*.

Order 5. Lithistidæ. Sponges with thick stony walls and very variable external form. The spicules (fig. 7, *d*, *e*) consist of four rays, or are irregular in form, the extremities of the rays branch or expand and are firmly interlocked with one another but do not fuse together. In addition to the skeletal-spicules there is generally a surface layer of trifid spicules or of discs. Flesh-spicules are also present. Several different types of canal-system occur. Owing to their solidity the Lithistids are preserved abundantly as fossils. They are rare in the Palæozoic, the earliest form being *Archæoscyphia* found in the Upper Cambrian of Canada; in the Ordovician and Silurian *Astylospongia* occurs; in the Carboniferous *Doryderma* etc. No forms belonging to this order have been found in the Devonian, Permian, or Trias, they are numerous in the Jurassic, attain their maximum in the Cretaceous, and are scarce in the Tertiary.

Verruculina. Irregular, fan- or funnel-shaped, attached by a short stalk. Oscula placed on prominent elevations on the upper, and sometimes also on the under

rarely be detected since it is filled with material in the same condition. Sometimes the silica of the spicules has been entirely removed, in some cases a hollow cast only remaining; in others its place is taken by another mineral, as for instance by calcite in the sponges from the Lower Chalk of Dover and Folkestone, by iron pyrites in *Protospongia* from the Menevian Beds of St David's, by iron peroxide in the sponges of the Upper Chalk of the south of England, by glauconite in some from the Upper Greensand. Obviously then silica in the colloidal state in which it occurs in recent sponges is anything but a stable substance, thus differing widely from its crystalline and crypto-crystalline condition.

The spicules of the calcareous sponges are usually smaller than those of the siliceous forms, and their material is not in an isotropic state, each one being optically a crystal of calcite but having the form and structure of a spicule; consequently in polarised light they are readily distinguished from the siliceous forms. Then again the fossil calcareous spicules have undergone much less chemical change than the siliceous ones; generally they are still composed of carbonate of lime, it is only in rare cases that this is replaced by silica, but at the same time the external form of the individual calcareous spicules is often less well preserved.

The canal-system is indicated in the skeleton of both recent and fossil forms, by spaces in the spicular framework, but these spaces represent only the larger canals, the smaller existing in the soft parts alone.

Reproduction in the sponges takes place by budding or gemmation, and sexually.

Various classifications of the sponges have been proposed by different authors; in the one adopted here the

ORDER 4. TETRACTINELLIDÆ. The spicules (fig. 7, *b*, *c*) are held together by spongin, they consist of four rays given off from a common centre, the angle between each of the rays being 120°. The rays may be equal or unequal in length, frequently one is very much elongated, and sometimes their terminations are bifurcated. Like the Monactinellids, the Tetractinellids are seldom preserved in anything like a perfect condition as fossils. The oldest forms occur in the Carboniferous Limestone, where they are represented by the genera *Geodites* and *Pachastrella*.

ORDER 5. LITHISTIDÆ. Sponges with thick stony walls and very variable external form. The spicules (fig. 7, *d*, *e*) consist of four rays, or are irregular in form, the extremities of the rays branch or expand and are firmly interlocked with one another but do not fuse together. In addition to the skeletal-spicules there is generally a surface layer of trifid spicules or of discs. Flesh-spicules are also present. Several different types of canal-system occur. Owing to their solidity the Lithistids are preserved abundantly as fossils. They are rare in the Palæozoic, the earliest form being *Archæoscyphia* found in the Upper Cambrian of Canada; in the Ordovician and Silurian *Astylospongia* occurs; in the Carboniferous *Doryderma* etc. No forms belonging to this order have been found in the Devonian, Permian, or Trias, they are numerous in the Jurassic, attain their maximum in the Cretaceous, and are scarce in the Tertiary.

Verruculina. Irregular, fan- or funnel-shaped, attached by a short stalk. Oscula placed on prominent elevations on the upper, and sometimes also on the under

surface. Spicules small, interlacing and forming a fibrous network. Chalk. Ex. *V. reussi*, Upper Chalk.

Pachinion. Cylindrical or club-shaped, tapering at its lower part to a short stem. Central cavity large and deep, with vertical canals opening into its base. Wall formed of anastomosing fibres, between which are irregular spaces—there are no distinct canals; there is also a surface layer composed of small spicules. Chalk. Ex. *P. scriptum*, Upper Chalk.

Doryderma. Cylindrical, pear-shaped, sometimes branching. There are parallel vertical canals opening at the summit of the sponge, and smaller radial canals extending from the surface towards the centre. Spicules large, of various forms; also a dermal layer formed of slender trifid spicules. Carboniferous and Cretaceous. Ex. *D. benetti*, Upper Greensand.

Siphonia (fig. 8). Pear-shaped, usually provided with a stalk, which is given off from the broad end of the body and terminates in rootlets. The incurrent

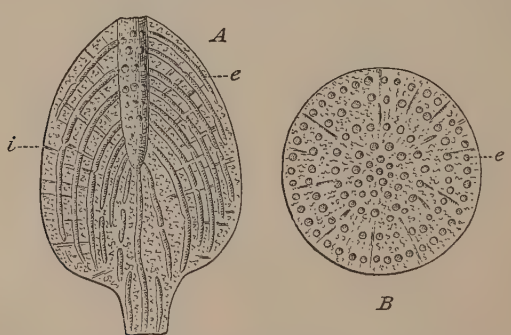


Fig. 8. *Siphonia tulipa*. Upper Greensand, Warminster. *A*, vertical section. *B*, horizontal section. *e*, excurrent canals; *i*, incurrent canals. Two-thirds natural size.

canals are small, slightly curved, and extend radially from the centre of the sponge to the surface. The excurrent canals are larger, and are arranged parallel to the surface of the sponge, extending from the base to the summit, where they open into the large central cavity by means of a series of parallel ostia. The skeletal-spicules possess four rays with bifurcated and expanded extremities, by means of which they are interlocked. Upper Greensand to Upper Chalk. Ex. *S. tulipa*, Upper Greensand.

Order 6. Hexactinellidæ. The spicules (fig. 7, *f*) consist of six rays (three axes) at right angles to one another. Each ray is traversed by an axial canal, and these unite at the point of junction of the six rays. In some cases one ray is longer or shorter than the others, or almost absent. The spicules are united so as to form a framework of skeleton cubes, either by being fused, or simply held in position by the soft parts. Flesh-spicules are abundant, but rare as fossils. The canal-system is usually simple. The earliest form is *Protospongia* from the Menevian Beds of St David's; *Hyalostelia* is found in the Tremadoc, and also occurs in the Ordovician, Silurian, and Carboniferous. In the Silurian the genera *Dictyophyton* and *Phormosella* are present. There are none in the Permian and Trias, but they become abundant in the Jurassic, especially in the upper part, and also in the Cretaceous; they are rare in the Tertiary. The sponge-character of the Silurian and Devonian genera *Ischadites*, *Receptaculites*, and *Sphærospongia*, which have been placed by some authors in this Order, is now disputed.

Protospongia (fig. 9). Form unknown but probably cup-shaped. Spicules cruciform, owing to the reduction of

one axis, and arranged in a quadrate manner, the larger forming a framework, which contains the smaller spicules of two or three sizes, arranged in the same regular way, so that the larger squares enclose four or five series of smaller ones. The spicules were either free or probably

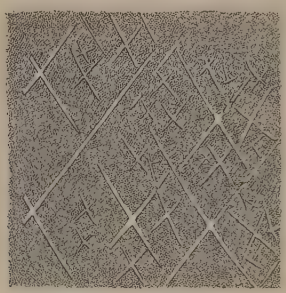


Fig. 9. *Protospongia fenestrata*, Menevian Beds, St David's. × 3¾. After Hinde. The original in the British Museum. Owing to the cleavage of the rock the angles of the spicules are distorted.

partly fused together. Menevian Beds and Lingula Flags. Ex. *P. fenestrata.*

Craticularia. Cup-shaped or cylindrical; simple or branching. On both the inner and outer surfaces of the wall are circular or oval canal-openings, which are arranged in vertical and transverse rows crossing each other at right angles. Canals straight, terminating blindly. Inferior Oolite to Upper Chalk (perhaps also Miocene). Ex. *C. fittoni,* Chalk.

Ventriculites. Simple, form variable, but usually cup-shaped, funnel-shaped, or cylindrical. Central cavity large and deep. Walls folded so as to form a series of vertical grooves and ridges. Canal-system well developed, the radial canals are large and start from the central

cavity, but end before reaching the outer surface; others start from the outer surface and end before reaching the central cavity. Spicules six-rayed and fused with one another so as to form a mesh-work. The node where the axes cross is hollow, having the form of a negative octahedron, the central part of each face of which is absent; the axial canals cross in the centre of the space. The sponge was provided with a root consisting of siliceous fibres. Upper Chalk. Ex. *V. radiatus, V. impressus.*

Plocoscyphia. Sponge formed of tubes and laminæ which anastomose forming an irregular or rounded mass. Canal-system imperfect. Upper Cretaceous. Ex. *P. fenestrata,* Upper Greensand and Chalk Marl.

Order 7. Octactinellidæ. The spicules (fig. 7, *g*), consist of eight rays, six of which are in one plane diverging at equal angles, the other two are at right angles to this plane, forming a vertical axis. Frequently, however, the vertical axis is only slightly developed or altogether absent. The spicules are not united. The only genus is *Astræospongia* found in the Silurian and Devonian.

Order 8. Heteractinellidæ. The spicules are unusually large (fig. 7, *h*), the number of rays varying from six to thirty. The body spicules are not fused, but there is a dermal layer in which the spicules are interwoven and more or less fused. The only genera are *Tholiasterella* and *Asteractinella* found in the Carboniferous rocks of Ayrshire.

CLASS II. CALCAREA.

(Calcispongiæ.)

The skeleton consists of spicules composed of carbonate of lime. The spicules are usually much smaller and less varied in form (fig. 7, *j*) than those of the siliceous sponges; there are three kinds, the simple uniaxial, the three-rayed, and the four-rayed; they are never fused with one another, and are either arranged close together so as to form fibres, or they are loosely distributed. The earliest forms in Britain occur in the Carboniferous rocks of Fifeshire.

Peronidella[1]. Cylindrical, simple or branched; central cavity tubular and extending from the summit to the base of the sponge. Walls thick and with no definite canals, the current of water having probably passed through the irregular spaces between the spicular fibres. Spicules three or four-rayed forming anastomosing fibres. Carboniferous (possibly also Devonian) to Cretaceous; most abundant in the Jurassic and Cretaceous. Ex. *P. pistilliformis*, Great Oolite and Cornbrash.

Elasmostoma. Leaf-like, sometimes cup- or funnel-shaped, walls thin. The upper (or concave) surface covered with a smooth dermal layer containing the openings of the oscula; under surface porous, without a dermal layer. Generally there is no canal-system. Spicules large, three-rayed, with other smaller thread-like spicules. Great Oolite to Chalk. Ex. *E. acutimargo*, Lower Greensand.

[1] Formerly known as *Peronella*; this name was given by Zittel in 1878, but had been previously used by Gray for a genus or sub-genus of Echinoderms. For this reason Zittel has modified the name of the sponge to *Peronidella*.

Distribution of the Porifera.

The Sponges are all aquatic, and, with the exception of the Monactinellid genus *Spongilla* and its allies, all marine. They are found in the seas of all parts of the world, many of the genera and species having a very wide distribution. All the orders except the Octactinellidæ and the Heteractinellidæ have living representatives. The Lithistids are found mainly between 10 and 150 fathoms, but some species occur at greater depths. The Hexactinellids occur in deeper water than the Lithistids, being found down to a depth of 2900 fathoms, but they are most abundant between 100 and 200 fathoms. The Calcarea are mainly shallow water forms.

The fossil forms are comparatively rare in the Palæozoic rocks, until we reach the Carboniferous; and throughout the geological formations they are much less abundant in argillaceous than in calcareous and arenaceous rocks. Sponges are first found in the Lower Cambrian rocks; the earliest British form is *Protospongia* from the Menevian Beds and Lingula Flags; in the Tremadoc the Hexactinellid genus *Hyalostelia* occurs, ranging onwards as far as the Chalk. In the Ordovician we have, in the Llandeilo Beds, the first appearance of *Ischadites* associated with *Hyalostelia*; in the Bala Beds we meet with *Astylospongia*. The most abundant Silurian form is *Ischadites; Astræospongia* and *Hyalostelia* also occur. Sponges are rare in the Devonian, but *Astræospongia*, *Sphærospongia*, and *Receptaculites* have been recorded. In the Carboniferous rocks, sponges become much more common, the siliceous spicules often forming thick beds of chert: the Monactinellids are represented by *Reniera*, the Tetractinellids by *Geodites*, the Lithistids by *Doryderma*, the Hexactinellids by *Hyalostelia*, and the Heteractinellids by *Tholias-*

terella and *Asteractinella*. Sponges appear to be absent in the Permian, and they are rare in the Trias, except in the St Cassian Beds of the Tyrol, where the Calcarea are numerous. In the Jurassic, sponges are extremely abundant; the only Monactinellid is *Spongilla* from the Purbeck Beds; Lithistids and Hexactinellids although abundant in Germany and Switzerland are rare in England, the first group is represented by *Platychonia*, the second by *Craticularia*, *Verrucocœlia*, etc.; the Calcarea are numerous in this country as well as in France and Germany, common genera being *Peronidella*, *Corynella*, and *Holcospongia*. In the Cretaceous, sponges are more abundant than in any other system; in England they are found chiefly at four horizons:—(1) in the Lower Greensand of Faringdon, Upware, Kent, and Surrey, where the Calcarea are much better represented than the other groups, *Peronidella*, *Elasmostoma*, and *Raphidonema*, being common forms: (2) in the Upper Greensand and Chloritic Marl of Warminster, Blackdown, Haldon, and the Isle of Wight; in these beds the Lithistids (*e.g. Doryderma*, *Siphonia*, *Hallirhoa*) are very abundant, exceeding the Hexactinellids (*e.g. Craticularia*, *Plocoscyphia*, *Stauronema*); the Calcarea are also common in places: (3) in the Lower Chalk of the south of England where we find *Siphonia*, *Craticularia*, *Stauronema*, *Plocoscyphia*, etc., the Calcarea are not represented: (4) in the Upper Chalk, where the siliceous sponges are very common; amongst the Lithistids the following occur:—*Seliscothon*, *Verruculina*, *Scytalia*, *Doryderma*, and *Siphonia;* the Hexactinellids are represented by *Craticularia*, *Verrucocœlia*, *Guettardia*, *Ventriculites*, *Cephalites*, *Plocoscyphia*, and *Camerospongia*. The Calcarea are rare. Lastly, in the Tertiary formations few sponges have been found.

III. CŒLENTERA.

Classes.		*Sub-Classes.*
1. Hydrozoa...	1.	Hydromedusæ.
	2.	Scyphomedusæ.
	3.	Graptolitoidea.
	4.	Stromatoporoidea.

	Orders.		*Sub-Orders.*
2. Actinozoa...	1. Zoantharia.	1.	Actinaria.
		2.	Antipatharia.
		3.	Madreporaria.
	2. Alcyonaria.		

3. Ctenophora (not fossil).

THE Cœlentera include the hydroids, jelly-fishes, corals, and allied forms. The individuals are radially symmetrical; the middle layer of the body-wall is very thin, and the canal-system, so characteristic of the sponges, is absent: stinging cells known as nematocysts or thread-cells are generally present. This group is divided into three classes, (1) the Hydrozoa, (2) the Actinozoa, (3) Ctenophora. (The last class is not found fossil.)

CLASS I. HYDROZOA.

In the Hydrozoa the digestive tract is not separate from the general cavity of the body (cœlenteron), and the latter is not divided into compartments by partitions (mesenteries). The simplest form of hydrozoan known is the common freshwater *Hydra*. In this the body consists of an elongated sac, at the free end of which is the mouth, while the other is the attached end. The interior of this sac is hollow and undivided, it is produced above into a row of tentacles surrounding the mouth; the whole body is very contractile and constantly changing its shape. Multiplication takes place (1) by the giving off of buds which ultimately separate from the parent, (2) by fission, and (3) sexually, by the production of ova and spermatozoa. The sexual elements in *Hydra* are developed in the outer layer of the body-wall or ectoderm. In many hydrozoans however, they are produced in another individual (medusa) which arises by budding, so that there is an alternation of a sexual with an asexual generation. In a large number of forms there are no hard parts, but others possess a skeleton formed by the ectoderm, which may consist of chitinous material as in *Sertularia*, or of carbonate of lime as in *Millepora*. Many hydrozoans are compound animals consisting of a number of individuals or polyps associated together. Nearly all the Hydrozoa are marine. They may be divided into four sub-classes, (1) Hydromedusæ, (2) Scyphomedusæ, (3) Graptolitoidea, (4) Stromatoporoidea.

SUB-CLASS I. HYDROMEDUSÆ.

The Hydromedusæ include amongst modern forms such genera as *Tubularia*, *Sertularia* and *Physalia*. Al-

ough there is frequently a chitinous or calcareous eleton, this sub-class is but poorly represented in the sil state. The living form *Hydractinia* is found in the etaceous and later formations[1]. The Hydrocorallinæ which the skeleton is calcareous, are also placed here, *illepora*, which ranges from the Eocene to the present y, being the best known genus.

SUB-CLASS II. SCYPHOMEDUSÆ.

The Scyphomedusæ include such jelly-fishes as *urelia*, *Rhizostoma*, and *Pelagia*, but they possess no rd parts; nevertheless the impressions of some forms *g. Rhizostomites*) have been found in the Lithographic mestone of Solenhofen.

SUB-CLASS III. GRAPTOLITOIDEA.

The graptolites are found only in the Lower Palæozoic cks, where, owing to their abundance and to the limited nge in time of both genera and species, they are of mense importance to the stratigraphical geologist. ey occur most commonly in argillaceous rocks, especially black shales, whilst they are rare in sandstones and nestones. The graptolites, like the modern *Sertularia*, re compound animals, consisting of a number of indi-duals or polyps united by a common *cœnosarc*, the whole

[1] *Dendrograptus* found in the Cambrian and Ordovician, and *Dictyonema* which ranges from the Cambrian to the Silurian, perhaps belong this group, but they have been placed by some authors in the ptolitoidea. In *Dictyonema* the skeleton is fan- or funnel-shaped, consists of radiating branches, which run nearly parallel with one ther, and are united by transverse fibres.

being protected by a skeleton of chitin. But the origina material of the skeleton is never preserved in the fossi

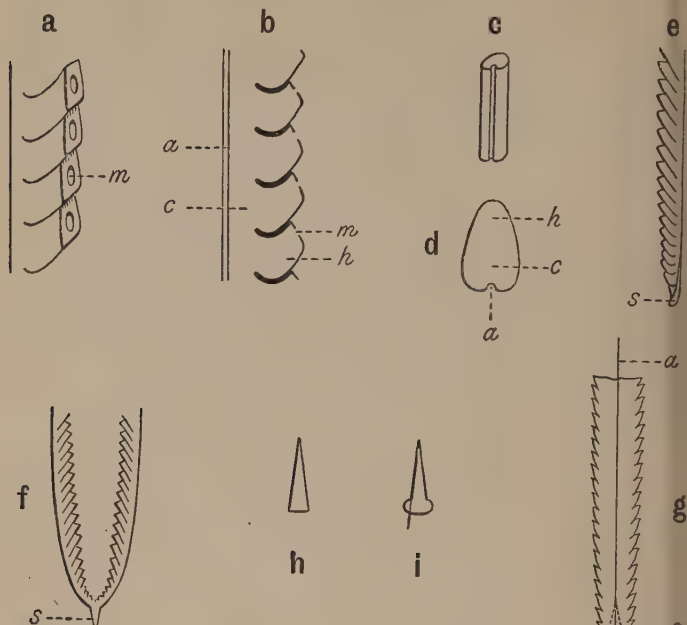


FIG. 10. Morphology of Graptolites. a, Portion of *Monograptus perso- natus*; b, vertical section of the same; c, *Monograptus* showing groove on the dorsal surface which was produced by the removal o the virgula; d, transverse section of *Monograptus* with virgul (N.B. Recent work has shown that the virgula is actually embedde in the periderm and *not* placed in a groove); e, *Monograptus colonus* Coniston Grits, with sicula(*s*); f, *Didymograptus murchisoni*, Llandeil Beds; g, *Diplograptus foliaceus*, Llandeilo Beds, with the positio of the imbedded sicula (*s*) indicated; h, sicula of *Diplograptus*, th earliest stage; i, the same with virgula and two buds developed (All enlarged except f.)

a, virgula; *c*, common canal; *h*, hydrotheca; *m*, mouth of hydrotheca *s*, sicula.

ite, its place being taken by carbon or by iron pyrites. he entire skeleton is termed the *polypary*; this in a mple form like *Monograptus* consists of a more or less lindrical tube known as the *common canal* (fig. 10 b, *c*), hich extends nearly the whole length of the animal, the ll being termed the *periderm*. From one side of the mmon canal small cups or tooth-like projections are ven off; these are the *hydrothecæ* (fig. 10 b, *h*), each which opens on the one hand into the common canal d on the other to the exterior; the latter aperture, own as the *mouth* (*m*) of the hydrotheca, is frequently cular, but sometimes quadrangular or slit-like. Em-dded in the periderm on the dorsal side of the common nal, that is on the side opposite to the row of hydrothecæ, a chitinous thread or rod, termed the *virgula* (fig. 10 d, *a*); some cases this is solid, in others it appears to be llow. In some species of *Monograptus* the virgula ojects beyond the distal[1] end of the common canal. At e proximal end of the polypary there is a small conical dy, termed the *sicula* (fig. 10 e, *s*) which will be described re fully below.

The soft parts of the graptolites are of course unknown, t from comparison with recent allied forms, we may nsider it probable that each hydrotheca lodged an lividual polyp, and these were connected by means of e cœnosarc which occupied the common canal.

In the form just described (*Monograptus*) the polypary always simple, but in many genera it consists of two more branches or stipes. When several branches are en off from a common centre, their proximal parts are metimes enclosed in a horny sheath termed the *central*

[1] The proximal end of the polypary is the part which is formed first, distal end is formed last.

disc, as in some species of *Tetragraptus* (fig. 11). In thos genera which have two branches (fig. 10 f), the term *angl of divergence* is applied to the angle between the hydr thecal margins. In some cases (*e.g. Monograptus,* fi 10 e) the polypary possesses only a single row of hydr thecæ, such forms are said to be *monoprionidian*; othe however (*e.g. Diplograptus,* fig. 10 g) possess two rows o opposite sides of the polypary, these are the *diprionidia* forms, and they may have a single common canal as i *Retiolites,* or there may be two canals separated by septum, as in *Climacograptus*: in many forms of *Diplo graptus* there is only one common canal, but other possess an imperfect septum which, to some extent, divide

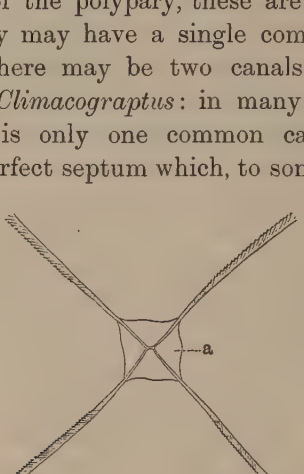


Fig. 11. *Tetragraptus headi,* from the Arenig Rocks. *a,* central disc. $\frac{1}{3}$ nat. size.

the canal into two parts. The genus *Dicranograptus* shows a transition between the monoprionidian and the diprionidian types, its proximal end being provided with two rows of hydrothecæ, whilst distally the polypary divides into two branches each bearing a single row.

The hydrothecæ vary considerably in form in differen genera, and sometimes even in different species of the same genus; but in the same species they are similar

xcept that they diminish in size towards the proximal nd of the polypary; they may be rectangular (*e.g. Phyllo-raptus*), tubular (*e.g. Rastrites*), conical (*e.g. Monograptus piralis*), or coiled (*e.g. Monograptus lobiferus*). They may e in contact throughout their entire length (*e.g. Phyllo-raptus*), at their bases only (*e.g. Cœnograptus*), or entirely eparate (*e.g. Rastrites*). Frequently they are provided ith one or more spines near the mouth. The hydrothecæ re said by most authors to communicate freely with the ommon canal, in this respect differing from the allied ving forms, in which there is a constriction, or a dia-hragm, at the base of each hydrotheca separating it from ne common canal. But Mc-Coy and Hopkinson state that n some specimens, as for in-tance *Didymograptus extensus*, *Didymograptus patulus*, and *Tetragraptus serra*, from the Skiddaw Slates, there is a istinct septum between the ydrothecæ and the common anal, and moreover in some ases the common canal itself s divided up by transverse epta.

A microscopic examina-ion of thin sections of *Mono-raptus* shows that the peri-erm consists of four layers; ne external and internal layers eing much thinner than the wo others. In *Retiolites* the eriderm is formed of a

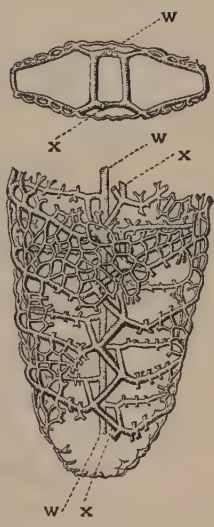


Fig. 12. *Retiolites geinitzi*, Silurian. A, section across polypary. B, Proximal end of polypary with the outer layer removed. Enlarged (after Holm). *w*, straight virgula. *x*, zigzag virgula.

network of fibres (fig. 12) covered by a continuous outer layer or epiderm. In the majority of cases the virgula is single, and is placed dorsally in the monoprionidian genera, but in the diprionidian forms it is central, being situated in the middle of the common canal, or placed in the septum separating the two canals as in *Climacograptus*. Occasionally, however, there are two virgulas, as in *Retiolites* (fig. 12 *w*, *x*), which are placed in the wall on opposite sides of the common canal. In several genera (*e.g. Didymograptus, Tetragraptus, Dichograptus, Dicranograptus*, and *Dicellograptus*) the virgula is absent, or, at any rate, has never yet been seen.

The position of the sicula also varies. In *Monograptus* it is united to the dorsal surface of the polypary, the pointed end being directed distally (fig. 10 e, *s*). In *Didymograptus* its broad end only is united to the polypary, the pointed end being directed downwards (fig. 10 f, *s*). In *Dicellograptus*, in which there are two branches diverging at a wide angle, it forms a kind of axial spine. In *Diplograptus* it is enclosed by the hydrothecæ (fig. 10 g, *s*).

The appearance of even the same species of graptolite varies considerably according to its mode of preservation. Frequently it is flattened to a film, and when this is the case we may get a side view, a front view showing the mouths of the hydrothecæ, or a back view; in the two latter cases the margins will be parallel. But when the original material has been replaced by iron pyrites, or when the graptolite is preserved in a limestone, the natural form of the polypary is retained.

The reproduction of the graptolites appears to have been similar to that which takes place in some modern hydrozoans. In a few diprionidian forms (fig. 13) sac-like

bodies have been found attached to the sides of the polypary; these, when perfect, are pear-shaped, and in some cases at any rate, are connected with the virgula by means of fibres. These bodies resemble in many respects the *gonangia* of living Sertularians,—chitinous sacs, within which in some forms (*e.g. Plumularia, Sertularia, Campanularia*) the *gonophores* are developed and give rise directly to the generative elements. The earliest condition of the graptolite at present known, is the *sicula* (fig. 14 A); this probably arises indirectly from the sac-like bodies which have been supposed to be gonangia. The mode of development of the graptolite from the sicula has been carefully studied in the genera *Monograptus* and *Diplograptus* (fig. 14). The sicula is a hollow cone open at the base; it consists of two parts—the pointed end with a thin wall (*b*), and the broader basal part with a thick wall marked with lines of growth (*a*). The pointed part was probably the covering of the embryo, and the broad part a later growth. In *Monograptus* a bud, which develops into the first hydrotheca (fig. 14, B 1), arises on one side of the sicula; and from this the second hydrotheca (2) is given off: each subsequent hydrotheca is produced in the same way from the one preceding. In *Diplograptus* one bud only is given off from the sicula;

Fig. 13. *Diplograptus whitfieldi*, with reproductive sacs. (After Hall.)

this becomes the first hydrotheca (fig. 14, C, 1); from this the second hydrotheca (2), which is on the opposite side, is given off; the later hydrothecæ (3, 4, etc.) arise from the one preceding on the opposite side. When, as in many forms of *Diplograptus*, the virgula projects beyond

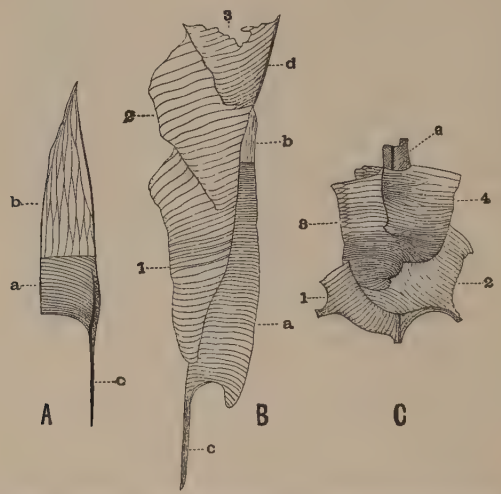


Fig. 14. Early stages of *Monograptus* and *Diplograptus* (after Wiman). Enlarged.

A. Sicula of *Monograptus*, from the Silurian of Gothland. *a*, thick-walled part with lines of growth; *b*, the earliest part with a thin wall; *c*, virgula.

B. *Monograptus* (same locality) with three hydrothecæ developed. 1, 2, 3, first, second, and third hydrothecæ; *a*, *b*, sicula; *c*, *d*, virgula.

C. *Diplograptus* from Bornholm, with four hydrothecæ developed. 1, 2, 3, 4, first, second, third and fourth hydrothecæ; *a*, sicula.

both ends of the polypary, it is not, as has usually been stated, a continuous rod, but consists of two distinct parts *c*, *d* (fig. 14 B); the distal part has grown out as a spine from the pointed end of the sicula, but the proximal part has been formed at the broad end.

Owing to the fact that the soft parts of the graptolites re entirely unknown, it is difficult to speak of their ffinities with any degree of certainty. There can be o doubt, however, that they belong to the Hydrozoa; llman and others have referred them to the Hydro-edusæ, placing them near such forms as *Sertularia* nd *Plumularia*, with which they agree in the general rrangement of the hydrothecæ, and in the possession of onangia. But they differ from them in possessing a irgula, in the diminution in size of the hydrothecæ owards the proximal end of the polypary, and in the ree communication which exists in many, if not all cases etween the hydrothecæ and the common canal.

Some authors have considered that the graptolites vere free-swimming animals; but it is very probable, hat some at any rate of them, were attached to sea-reeds or other foreign objects. Ruedmann has recently escribed a specimen of *Diplograptus pristis*, from the Utica Slate of New York, which consists of a number of ndividuals radiating from a central body to which they re attached by the distal ends of their virgulas; this entral body is considered to have been a floating organ milar to the pneumatocyst found in existing Siphono-hora, such as *Physalia* (the 'Portuguese man-of-war').

The genera of graptolites at present accepted are ased, to a large extent, on the number of branches of he polypary; but Nicholson and Marr have recently hown that this feature is of little importance, and that classification which shows the genealogical relationships the forms can be founded on the characters of the drothecæ and the angle of divergence of the branches. he most ancient graptolites, such as *Bryograptus*, appear, first sight, to be more complex than the later types

(*e.g. Monograptus*), on account of their branching; but in the early forms the hydrothecæ are very simple, differing but little from the sicula, whereas in the later ones they exhibit considerable modification. In some genera the hydrothecæ of different species show great variety of form; those of one species being often much more like those of a species belonging to another genus than to other species of the same genus: thus we get the same type of hydrotheca in the three forms *Bryograptus callavei, Tetragraptus hicksi,* and *Didymograptus affinis*; and another type in *Bryograptus retroflexus, Tetragraptus denticulatus,* and *Didymograptus fasciculatus*: it is contended that each of these groups is a genealogical series and should be regarded as a genus—that *Tet. hicksi* has descended from *B. callavei,* and *Did. affinis* from *T. hicksi.* According to the old view all the species of *Didymograptus* were thought to have descended from one ancestor; but this will not account for the close resemblance which the hydrothecæ of certain species of *Didymograptus* bear to certain species of *Tetragraptus*; on the other hand, this is readily explained if we consider that the species of *Didymograptus* have descended from various species of *Tetragraptus.* Then again the remarkable diversity in the hydrothecæ of *Monograptus* can be easily understood if we grant that the forms included under this term are the descendants of different species of one or more genera. Now since species which have a different ancestry cannot be placed in the same genus we must regard *Monograptus* as an assemblage of forms which simply agree in consisting of one simple monoprionidian branch or stipe.

It has been suggested that the similar modification in branching found in different forms may have been brought about by food-supply—the larger the number of branches

the smaller would be the total supply of food for each individual of a colony; consequently when one species of a four-branched type (*Tetragraptus*) had become a two-branched form, it would have a considerable advantage over the remaining four-branched forms, which would, as a result, soon die out.

Monograptus. (fig. 10 e.) Polypary simple, monoprionidian, straight, curved or spiral. Hydrothecæ vary in form in different species. The sicula is attached to the dorsal side of the proximal end of the polypary; its pointed end is directed distally. Lower Llandovery to Lower Ludlow. Ex. *M. nilssoni*, Lower Ludlow; *M. leptotheca*, Llandovery; *M. priodon*, Wenlock; *M. spinigerus*, Llandovery.

Rastrites. Polypary similar to *Monograptus*, but the common canal is very narrow, and the hydrothecæ are long and widely separated. Llandovery to Tarannon. Ex. *R. peregrinus*, Llandovery to Tarannon.

Cyrtograptus. Polypary similar to *Monograptus*, but coiled into a plane spiral and with branches given off from the hydrothecal margin. Upper Tarannon to Lower Ludlow. Ex. *C. murchisoni*, Wenlock Shale.

Leptograptus. Polypary consisting of two simple, slender, flexuous, monoprionidian branches, given off in opposite directions from the broad end of the sicula. Upper Llandeilo to Lower Bala. Ex. *L. flaccidus*, Upper Llandeilo and Lower Bala.

Cœnograptus. Polypary bilateral, monoprionidian. The central non-celluliferous portion bent into an S-shape, giving off branches from the convex portions. Hydrothecæ in contact only, not overlapping. Sicula triangular, placed

at the centre of the polypary. Upper Llandeilo. Ex. *C. gracilis.*

Didymograptus. (fig. 10 f.) Polypary bilateral, monoprionidian, consisting of two simple branches diverging at an angle which varies from 0° to 180° (or occasionally greater) in different species. Hydrothecæ rectangular, in contact. The pointed end of the sicula directed downwards. Lower Arenig to Upper Llandeilo. Ex. *D. murchisoni,* Lower Llandeilo; *D. patulus,* Arenig.

Tetragraptus. (fig. 11.) Polypary bilateral, monoprionidian, consisting of four simple radiating branches. Hydrothecæ rectangular, in contact. A central disc may or may not be present. Lower Arenig. Ex. *T. quadribrachiatus.*

Dichograptus. Polypary monoprionidian, consisting of four branches which soon bifurcate. Hydrothecæ rectangular. A central disc is frequently present. Lower Arenig. Ex. *D. octobrachiatus.*

Dicranograptus. Proximal portion of the polypary diprionidian, but dividing distally into two monoprionidian branches. Terminations of the hydrothecæ isolated and incurved. Upper Llandeilo to Lower Bala. Ex. *D. clingani,* Bala.

Dicellograptus. Like *Dicranograptus,* but monoprionidian throughout, the two branches united by the sicula only. Angle of divergence greater than 180°. Upper Arenig to Upper Bala. Ex. *D. anceps,* Upper Bala.

Diplograptus. (fig. 10 g.) Polypary diprionidian. Hydrothecæ overlapping, and placed obliquely. Virgula prolonged beyond the distal and sometimes also the

proximal extremity of the polypary. Sicula imbedded. Lower Arenig to Tarannon. Ex. *D. foliaceus*, Llandeilo to Lower Bala.

Climacograptus. Polypary diprionidian. Hydrothecæ placed vertically and separated by deep depressions. Virgula prolonged beyond both extremities. Lower Arenig to Tarannon. Ex. *C. normalis*, Llandovery and Tarannon.

Phyllograptus. (fig. 15.) Polypary leaf-like, formed of four monoprionidian branches united along the whole of their dorsal surfaces. Hydrothecæ rectangular, in contact throughout their entire length, and furnished with two strong spines. Arenig. Ex. *P. typus*, Lower Arenig.

Fig. 15. *Phyllograptus*, Arenig Rocks. The polypary has been cut in two, and the upper part raised so as to show the four branches. Natural size.

Retiolites. (fig. 12.) Polypary simple, diprionidian, narrower at the ends. There are two virgulas, one is straight, the other zigzag; they are placed in the opposite walls of the polypary. Hydrothecæ rectangular, alternating, given off from a single common canal. Inner layer of the periderm is in the form of a network of rods or threads. Lower Bala to Wenlock. Ex. *R. geinitzianus*, Upper Tarannon and Lower Wenlock.

Distribution of the Graptolitoidea.

In Britain the oldest graptolites occur in the Tremadoc Beds, where we find the genus *Bryograptus*; in the *Olenus*-shales of West Gothland, *Dichograptus* and *Clono-*

graptus also occur. These forms are also present in the lower part of the Arenig Beds, but other genera such as *Tetragraptus* and *Didymograptus*, are associated with them and soon become abundant; *Phyllograptus* also occurs here. The Llandeilo graptolites are transitional between the Arenig and Bala forms, *Phyllograptus* is absent, *Didymograptus* is fairly common in the lower part, and the genera *Dicellograptus, Dicranograptus, Diplograptus* and *Climacograptus* now appear for the first time. In the Bala Beds, the four last-mentioned genera become much more abundant, and with them occur *Leptograptus* and *Pleurograptus*. The only genera which pass up from the Bala

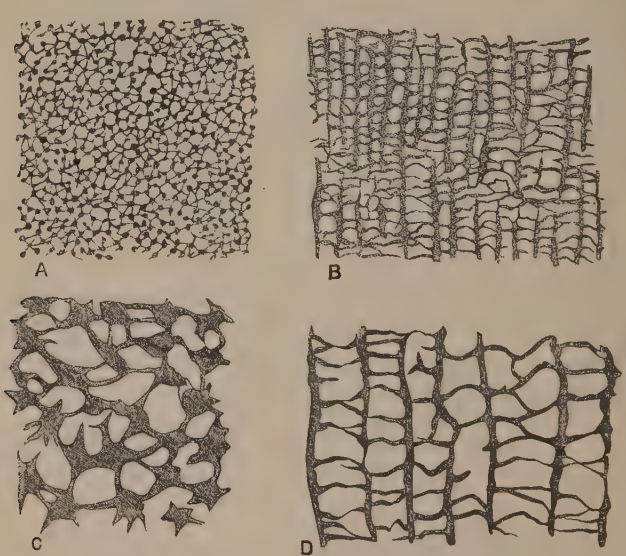


Fig. 16. A, Tangential section of *Actinostroma intertextum* showing the radial pillars. B, vertical section showing the radial pillars and the formation of the concentric laminæ by processes given off from these. × 12. C and D, parts of the same further enlarged. From the Silurian Rocks. (After Nicholson.)

to the Silurian are *Climacograptus, Diplograptus,* and *Retiolites*; not a single Bala species (except perhaps a variety of *Climacograptus scalaris*) is found in the Llandovery Beds, so that between the Ordovician and Silurian there is an enormous break in the graptolitic succession. As a whole the Silurian formations are characterised by the presence of the family *Monograptidæ*[1], which appears first at the base of the Llandovery Beds. In the lower part of the Llandovery the genera *Diplograptus* and *Climacograptus* are fairly abundant, but they become extinct in the Tarannon, and in the Wenlock and Ludlow Beds the only forms are *Monograptus, Cyrtograptus,* and *Retiolites.* The last traces of graptolites occur in the Downtonian Beds, but they are too imperfect for determination.

SUB-CLASS IV. STROMATOPOROIDEA.

In the Stromatoporoids the skeleton is calcareous[2], and very variable in form; it may be hemispherical, spheroidal, hemispheroidal, encrusting, or altogether irregular, and frequently forms large masses. It consists of a series of concentric laminæ separated by spaces; these are crossed at right angles by rods or pillars, which give off horizontal processes at definite intervals; these processes join together and really form the laminæ. In some genera, as for example *Actinostroma* (fig. 16), the two elements of the skeleton—the laminæ and pillars, remain quite distinct, but in others like *Stromatopora,* they become to a great extent blended together so as to form a more or less netted structure. The Stromatoporoids were compound animals, the polyps

[1] This includes the genera, *Monograptus*, *Rastrites* and *Cyrtograptus*.

[2] In some specimens the carbonate of lime has been dissolved and its place taken by silica.

in some cases simply occupying pores in the externa lamina, in others there were definite tubes. The members of this group are most closely related to such living forms as *Hydractinia* and *Millepora*. They are found only in the Ordovician, Silurian, and Devonian Systems, being most abundant in the last; frequently they are of considerable importance as rock-builders. Some of the best known genera are *Labechia*, *Stromatopora*, *Actinostroma*, and *Clathrodictyon*.

CLASS II. ACTINOZOA.

This class includes the corals and sea-anemones They differ from the Hydrozoa (1) in possessing an alimentary tube, which is distinct from the cœlenteron though opening into it; (2) in having the cœlenteron divided up into chambers by vertical radiating partitions known as mesenteries; (3) in the reproductive elements being developed in the endoderm of the mesenteries and never on a medusa.

The Actinozoa possess an apparent radial symmetry

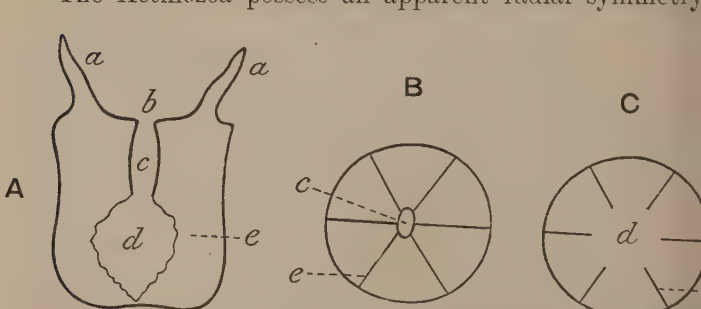


FIG. 17. Diagrammatic sections of a sea-anemone. *A*, vertical; *B*, horizontal, through the upper part of the polyp. *C*, through the lower part. *a*, tentacles; *b*, mouth; *c*, œsophageal tube; *d*, cœlenteron; *e*, mesenteries.

but closer examination reveals a bilateral arrangement of their parts. In a typical form, such as the common sea-anemone *Actinia*, the body has a more or less cylindrical form, and is attached by one end, the other having an opening, the mouth (fig. 17 *b*), surrounded by tentacles (*a*). The mouth leads into the *œsophageal tube* (*c*), which opens at its lower end into the cœlenteron (*d*). The latter is divided into chambers by radiating partitions, the *mesenteries* (*e*); in the upper part of the polyp, their inner edges join the œsophageal tube, in the lower part they remain free, so that a section in the former region (fig. 17 *B*) will show the body wall and also the œsophageal wall, but in the latter (*C*) the body wall only. The tentacles (*a*) are placed immediately above the intermesenteric chambers, and the space in each tentacle is continuous with that of the chamber below. In the sea-anemones there are no hard parts, but the majority of actinozoans possess a skeleton, which in many cases is quite external to the body, and is formed of carbonate of lime; in others it is internal and may consist of calcareous spicules, or of an axial rod of horny or calcareous material. The Actinozoa are divided into two orders, (1) the Zoantharia, (2) the Alcyonaria.

ORDER I. ZOANTHARIA.

In the Zoantharia the tentacles and mesenteries are generally numerous and are never eight in number as is the case in the Alcyonaria, but frequently a multiple of six or sometimes four. The tentacles are always simple. A skeleton is often present and may be calcareous or horny; when calcareous it is never composed of spicules but consists of bundles of aragonite fibres.

There are three sub-orders, (1) the Actinaria, o sea-anemones, which possess no skeleton and are con sequently unknown in the fossil state; (2) the Anti patharia, in which the skeleton consists of an interna horny rod secreted by the ectoderm; these also are no found fossil; (3) the Madreporaria, including the well known stony corals, which possess a calcareous skeleto and are very abundant as fossils.

SUB-ORDER III. MADREPORARIA.

In the Madreporaria there is a skeleton consisting c carbonate of lime, secreted by the ectoderm of the lowe part of the polyp. The entire skeleton is spoken of a the *corallum* and may be simple or compound; in th latter case each individual is termed a *corallite*. Th parts of the skeleton may be solid, or they may b perforated, or formed of a network of rods.

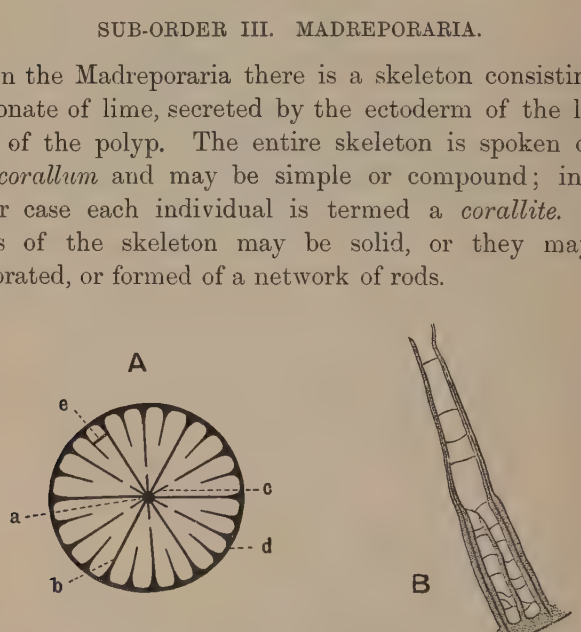


FIG. 18. *A*. Diagrammatic section (horizontal) of a simple cora *a*, columella; *b*, primary septa; *c*, pali; *d*, theca; *e*, dissepiments.

B. Portion of a horizontal section of *Cyathophyllum murch soni*, Carboniferous Limestone, showing the septa composed of thin middle layer with a thicker layer on each side; dissepimen near the margin. Magnified.

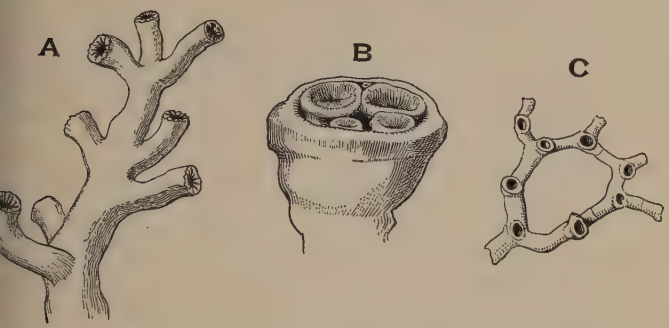
In a typical simple coral the skeleton has a more or ess conical form; the base of the cone is usually depressed nd is termed the *calyx*, in it the polyp was placed. The vall bounding the corallum is known as the *theca* (fig. 8 *A*, *d*); sometimes there is, outside this, another alcareous layer, the *epitheca*. The whole space enclosed y the theca is termed the *visceral chamber*; this is livided up by various calcareous partitions, the most mportant of which are the *septa* (fig. 18 *A*, *b*). These re vertical plates extending from the theca towards the entre, and alternating with the mesenteries. They are f different sizes, some reaching the centre, others being horter; they frequently occur in series or cycles, of which three or more may often be distinguished, the argest being the *primary* (*b*), the others the *secondary*, *ertiary*, etc. In some forms one or more of the primary epta are absent, and we have what are known as *septal ossulæ*. When the septa project upwards above the edge f the theca, they are said to be *exsert* (fig. 19). Sometimes they are absent or only feebly developed, and may be represented by rows of spines. When seen in section the septa re frequently found to consist f three layers (fig. 18 *B*), the niddle being darker and thinner than the outer, and apparently representing the original eptum, the outer layers having been formed subsequently. n the centre of the visceral chamber, where the larger septa neet, there is often a vertical rod, which extends from the ase of the chamber to the bottom of the calyx; this is the olumella (figs. 18 *A*, *a*; 22 *c*). Its structure varies

Fig. 19. *Montlivaltia trochoides*, Inferior Oolite, showing exsert septa. $\times \frac{1}{2}$.

considerably; when it is solid and ends in a knob or point in the calyx, it is said to be *styliform*; sometimes the top is porous or *spongy*. When the columella consists of twisted laminæ it is termed *trabeculate*; if formed by the twisting together of processes given off from the inner edges of the septa, it is *false*: in some genera there is no columella. Another set of vertical partitions somewhat similar to the septa are the *pali* (fig. 18 *A*, *c*); these are radiating plates attached to the columella and placed opposite the inner edges of some of the shorter septa, but not joining them. Passing from one septum to another are often rods, known as *synapticulæ*. Similarly connecting two septa, are plates, which may be horizontal or oblique, straight or curved; these are the *dissepiments* (figs. 18 *A*, *e*; 22 *d*); in some genera they are very abundant near the margin of the visceral chamber and form a spongy or *vesicular* tissue. Lastly we have the *tabulæ* (fig. 22 *B*, *t*), which are more or less horizontal plates occupying the central part of the visceral chamber or, when well developed, extending quite across it; they are arranged one above another, so that the visceral chamber is divided into horizontal compartments. On the outside of the wall of the coral there are in some forms vertical ridges, which may be smooth or spiny; these are known as the *costæ*, and they usually correspond in position with the septa.

A simple coral like that just described may become compound either by giving off buds, or by fission. Three kinds of budding may be distinguished, (1) the *lateral* (fig. 20 *A*), in which the buds are given off from the sides of the polyp, (2) the *calicular* (fig. 20 *B*), in which they arise from the calyx, (3) the *basal* (fig. 20 *C*), in which the buds spring from branches or stolons, which are given

ff from the base of the corallite. Fission commences by he mouth becoming slightly constricted, this goes on ntil two distinct mouths and two polyps are formed; a imilar division takes place in the skeleton. When the ndividual corallites in a compound form are free from one



g. 20. *A. Dendrophyllia nigrescens*, showing lateral budding, Recent. Reduced one-half. *B. Cyathophyllum truncatum*, showing calicular budding, Wenlock Limestone. Natural size. *C. Cladochonus crassus*, showing basal budding, Carboniferous Limestone. Natural size.

nother, the corallum is termed *dendroid* (fig. 20 *A*); hen they are in contact, it is *massive*. Sometimes the paces between the individual corallites are filled up with lcareous material formed by the cœnosarc, and known as ne *cœnenchyma*.

By most authors the Madreporaria have been divided into three ctions, (1) the Aporosa, (2) the Rugosa, and (3) the Perforata. ecent researches, however, seem to show that this classification n no longer be maintained, and particularly that the Rugosa nnot be separated from the Aporosa and Perforata. A more tural grouping can be based on the microscopic structure of the pta. For convenience of reference the characters of the three oups mentioned may be briefly stated thus:—(i) *Aporosa*, the eca and septa are solid, and the latter are generally in multiples

of six. Ex. *Montlivaltia*, *Parasmilia*, *Isastræa*, *Thecosmilia*, *Holocystis*. (ii) *Rugosa*, the skeleton is solid and the septa ar usually in multiples of four. This group is confined to th Palæozoic. Ex. *Cyathophyllum*, *Acervularia*, *Lithostrotion*, *Om phyma*, *Clisiophyllum*, *Lonsdaleia*, *Zaphrentis*, *Amplexus*, *Cyst phyllum*, *Calceola*. (iii) *Perforata*, the skeleton is porous or forme of a network of rods. Ex. *Litharæa*.

Formerly one of the divisions of the Madreporaria was th *Tabulata*, characterised by well developed tabulæ, and rudimen tary septa; it is probable that some of the genera placed in thi group really belong to the Alcyonaria. It included amongst others the following, *Heliolites*, *Favosites*, *Syringopora*, and *Halysites*.

Montlivaltia (fig. 19). Corallum simple, fixed o free; turbinate, cylindrical, or discoidal. Epitheca wel developed, theca thin. Columella absent. Septa nume rous, strong, often exsert, the upper edges dentate. Dis sepiments abundant. Trias to Recent. In England Lias to Corallian. Ex. *M. trochoides*, Inferior and Grea Oolites.

Parasmilia. Corallum simple, fixed, turbinate o elongated. Calyx circular. Columella spongy. Septa well-developed, exsert, granular on the sides. Wall with costæ. Cretaceous to present day; in England, Chalk Ex. *P. centralis*, Chalk.

Isastræa. Compound, massive; calyces polygonal Walls of the corallites fused along their entire length Columella rudimentary or absent. Septa thin and clos together. Dissepiments fairly abundant. Trias to Eo cene; in England, Lias to Upper Greensand. Ex. *I. ex planata*, Corallian.

Thamnastræa. Compound, massive; convex o laminar. Walls of the corallites indistinct. Calyce shallow. Septa of adjoining corallites confluent. Colu mella variable. Dissepiments present, synapticulæ nume

ous. Trias to Miocene; in England, Lias to Upper Greensand. Ex. *T. arachnoides*, Corallian.

Thecosmilia. Compound, dendroid or rarely almost massive. Multiplication by fission. Margin of calyces irregular. Columella rudimentary or absent. Septa strong, upper edges dentate, and more or less exsert. Dissepiments abundant. Epitheca thick and folded, but often not preserved. Trias to Tertiary; in England, Lias to Kimeridge Clay. Ex. *T. annularis*, Corallian and Kimeridge Clay.

Holocystis. Compound, massive, convex; calyces polygonal. Columella very small. Corallites united by their walls or by costæ. The four primary septa are much better developed than the others. Tabulæ well developed. Lower Greensand. Ex. *H. elegans*.

FIG. 21. *Cyathophyllum murchisoni*, Carboniferous Limestone. Portion of a vertical section. *d*, dissepiments; *t*, tabulæ. For horizontal section see fig. 18 *B*.

Cyathophyllum (figs. 18 *B*, 21). Simple or compound: often massive. Septa numerous, of two sizes, alternating, the longer giving rise to a false columella. Tabulæ rather small, occupying the central part only of the visceral chamber. Dissepiments form an extensive peripheral zone of vesicular tissue. Bala to Carboniferous Limestone. Ex. *C. murchisoni*, Carboniferous.

Acervularia. Compound, massive; corallites with two walls, the outer polygonal, frequently hexagonal, the inner circular. Septa well developed, reaching the centre. Columella absent. Tabulæ extend across the central part

of the visceral chamber. Dissepiments form a peripher zone of vesicular tissue. Silurian to Devonian. E *A. ananas*, Silurian.

Lithostrotion (fig. 22). Compound, massive or den droid. When massive the corallites are prismatic, whe dendroid they are cylindrical. Septa well developed alternately long and short. Columella styliform, laterall

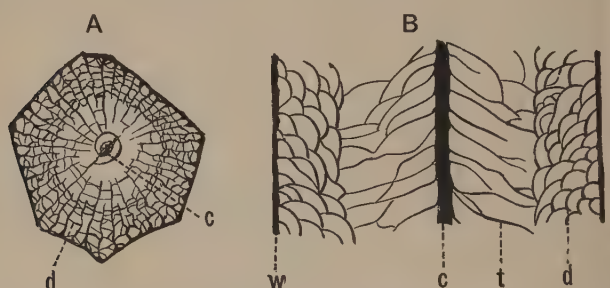


Fig. 22. *Lithostrotion basaltiforme*, Carboniferous Limestone. *A*. Hor zontal section of a single corallite, $\times 2\frac{1}{2}$. *B*. Vertical section, $\times 5$ *c*, columella; *t*, tabulæ; *d*, dissepiments; *w*, theca.

compressed. Peripheral zone of dissepiments narrow Tabulæ wide, occupying the centre of the viscera chamber. Septal fossulæ often well marked. Carbon ferous Limestone. Ex. *L. basaltiforme.*

Omphyma. Simple, turbinate. Septa numerou alternately long and short, but extending only a sho distance into the visceral chamber, the central part bein occupied by the tabulæ. The four primary septa ar placed in shallow fossulæ. No columella. Peripher zone of dissepiments narrow. The theca gives off roo like processes. Bala to Lower Ludlow. Ex. *O. subtu binata*, Wenlock Limestone.

Clisiophyllum (fig. 23). Simple, turbinate or sub-ylindrical. Septa numerous, alter-ately long and short; a well marked eptal fossula. In the centre of the isceral chamber is a large 'pseudo-olumella,' which consists of vertical adiating plates crossed obliquely y vesicular tabulæ; this structure rms a prominent projection at ne bottom of the calyx. The seudo-columella is surrounded by zone formed of tabulæ, and exter-al to this is a large zone of dissepi-ents. Carboniferous Limestone. x. *C. bipartitum.*

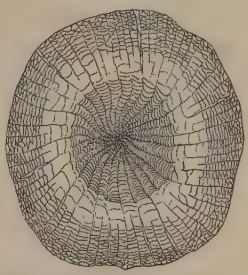


Fig. 23. *Clisiophyllum bipartitum*, Carboniferous Limestone. Horizontal section showing the large central 'pseudo-columella.' Natural size.

Lonsdaleia. Similar to the preceding, but com-ound, and the septa do not reach the wall of the rallite. Carboniferous Limestone. Ex. *L. duplicata.*

Zaphrentis. Simple, free, bilateral; turbinate, coni-l or cylindrical, often curved; calyx deep. A well arked septal fossula, containing a septum which is nerally small. Septa numerous. Tabulæ well developed, tending quite across the visceral chamber. Dissepiments w, never forming a peripheral vesicular zone. Columella sent. Theca thick. Wenlock Limestone to Carboni-rous Limestone. Ex. *Z. enniskilleni*, Carboniferous.

Amplexus. Similar to *Zaphrentis*, but the corallum generally cylindrical, and the septa are very short. evonian and Carboniferous. Ex. *A. coralloides*, Car-niferous.

Cystiphyllum. Simple, conical. Septa and tabulæ sent or rudimentary, the visceral chamber being filled

with vesicular tissue, the outer part consisting of dissepi ments, the central part representing tabulæ. Columell absent. Calyx shallow, often with ridges representin septa. Silurian and Devonian. Ex. *C. vesiculosum* Devonian.

Calceola (fig. 24). Simple, conical or slipper-shaped one side is flat, the opposite convex; calyx very deep an

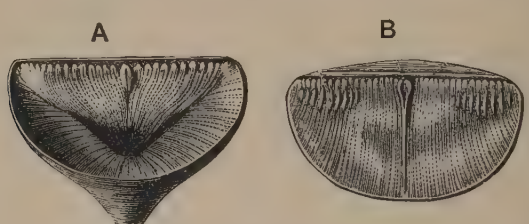


FIG. 24. *A. Calceola sandalina*, from the Middle Devonian; *B.* Operculu of the same. Natural size.

closed by a semi-lunar operculum, which has on its inne surface a strongly marked median ridge and several les prominent lateral ridges; septa indicated by striæ. A epitheca is present. Middle Devonian. Ex. *C. sandalin*

An operculum also occurs in the genera *Goniophyllu* and *Rhizophyllum*, which are found in the Silurian, an in the recent Alcyonarian *Primnoa*.

Litharæa. Compound, massive. Calyces more less polygonal. Septa well developed, the faces spiny, th upper edges dentate. Walls of the corallites reticulat Columella formed by the ends of the septa. Eocene Miocene. Ex. *L. websteri*, Bracklesham Beds.

ORDER II. ALCYONARIA.

The Alcyonaria are nearly all compound organisms; ney possess eight mesenteries and eight tentacles, the latter eing provided with pinnules. The nature of the skeleton aries considerably; in *Alcyonium* it consists of isolated picules embedded in the soft parts. In some cases it has ne form of an axial rod surrounded by the cœnosarc; this od may consist of horny material (*e.g. Gorgonia*) or of arbonate of lime (*e.g. Corallium*); in *Isis* it is formed artly of horny material and partly of carbonate of lime. n the 'organ-pipe coral' (*Tubipora musica*) the skeleton external and consists of numerous parallel tubes or rallites which are not in contact but are connected horizontal calcareous plates or 'platforms.' The walls the corallites, although apparently quite compact, e really composed of spicules which have serrated lges and are firmly fitted together. A single polyp es in each corallite. The interior of the corallite divided up by tabulæ which are often funnel-shaped. *ubipora* presents many points of resemblance to the alæozoic genus *Syringopora*, but in the latter the skele- n is apparently not composed of spicules and the plat- rms are absent, the corallites being joined together by onnecting-tubes.'

In some of the Alcyonaria, as for example *Pennatula*, ere are in addition to the ordinary polyps (or *autozooids*) hers of a more rudimentary character in which tentacles e absent, these are known as *siphonozooids*[1].

[1] The Monticuliporoids, which range from the Ordovician to the rmian, and include *Monticulipora*, *Fistulipora*, etc., perhaps belong to Alcyonaria, but they are placed by some authors in the Polyzoa.

Favosites. Compound, massive, sometimes branched Corallites long and polygonal; the walls are in contac but not fused, and are perforated by pores ('mura pores') arranged in rows along each face. Sept absent or represented by rows of spines. Tabulæ nume rous, regular, generally extending quite across the viscera chamber. Bala to Carboniferous Limestone. Ex. *F gothlandica*, Silurian.

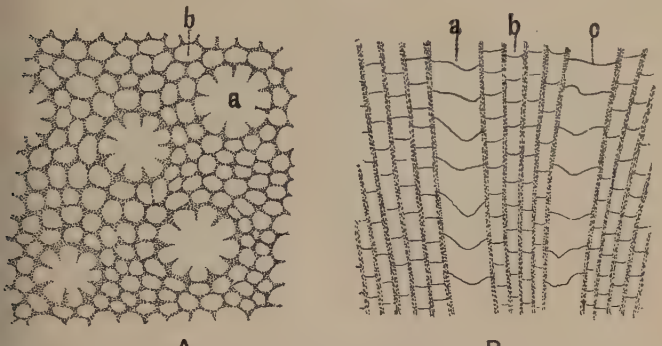
Pachypora. Similar to *Favosites*, but the walls o the corallites are greatly thickened, especially near th surface of the coral, by a secondary deposit of carbonat of lime. Silurian to Carboniferous. Ex. *P. cervicorni* Devonian.

Pleurodictyum. Compound, discoidal, attached b part of the base, upper surface slightly convex. Corallite diverge from the centre of the base; walls thick, wit irregular pores. Septa rudimentary. Tabulæ not numerou more or less united. Silurian and Devonian. Ex. *P. prob lematicum*, Devonian.

Michelinia. Similar to *Pleurodictyum*, but th tabulæ are more numerous and form a vesicular tissu and root-like processes are usually given off from th epitheca on the base of the coral. Devonian and Car boniferous. Ex. *M. favosa*, Carboniferous.

Syringopora. Compound; corallites tubular, for th most part not in contact, more or less parallel. Th visceral chambers of the different corallites are place in communication by means of horizontal connectin tubes. Septa feebly developed, generally represente by rows of spines. Tabulæ numerous, funnel-shape Budding basal. Llandovery to Carboniferous Limeston Ex. *S. reticulata*, Carboniferous.

Heliolites (fig. 25). Corallum compound, massive r branching, formed of tubes of two sizes, the larger



IG. 25. *Heliolites porosus*, Devonian. *A*. Horizontal section. *B*. Vertical section. *a*, autopores; *b*, siphonopores; *c*, tabulæ. Enlarged.

ircular ones are known as autopores, between these come ne smaller polygonal siphonopores. Tabulæ occur in oth, and in the autopores there are septa also, which nay be lamellar, spiny, or rudimentary, and are often welve in number. Bala to Devonian. Ex. *H. porosus*, Devonian.

Halysites. Compound; corallites long and tubular, ranged in a single row and united at their sides so as to rm laminæ, which intersect; in some species the coral-tes are of two sizes. Epitheca thick. Septa absent or epresented by spines. Tabulæ well developed, horizontal concave. Llandeilo Beds to Wenlock Limestone. Ex. *. catenularia*, Wenlock Limestone.

The systematic position of the genera *Favosites*, *Pachypora*, *Neurodictyum*, *Michelinia* and *Syringopora* is uncertain; by some thors they are placed in the Madreporaria.

Distribution of the Actinozoa.

From the point of view of their distribution at the present day, the Madreporaria may be divided into two groups, the solitary and the reef-building. The solitary corals are almost entirely confined to deep water, occurring down to at least 2,900 fathoms, and are found in almost all latitudes. The species likewise have a wide distribution, being apparently but little affected by conditions of temperature and depth. It might therefore be expected that they would also have a long range in time; this however is not the case, for existing forms extend but a short way back into the geological record, thus not a single living species is found fossil in the English Cainozoic formations. The distribution of the reef-building corals unlike that of the solitary forms is limited by both depth and temperature. Thus they are found only in shallow water, not usually extending lower than 20 or 30 fathoms; and only where the temperature of the ocean is not less than 68° F.; flourishing best in water even warmer than this. Like the solitary corals, the reef-building genera of the present day have but a very limited geological range. As a general rule, corals can only exist in salt water; there are however one or two exceptions thus *Cylicia rubeola* flourishes in the river Thames, New Zealand. Clear water is likewise generally necessary, but one species, *Porites limosa*, thrives in muddy situations. In geological times the reef-building corals had a much wider geographical range than they have at the present day, and occur abundantly in various formations in both temperate and polar regions.

The Alcyonaria occur in all parts of the world, and are

found at all depths from the shore-line down to 2,300 fathoms, but they are most abundant at depths of less than 100 fathoms; beyond this limit the number of species gradually diminishes as the depth of the water increases.

The Palæozoic families of the Alcyonaria are almost entirely unrepresented in later formations, and very few of the modern forms occur fossil, but *Corallium* is found in the Jurassic, and forms allied to *Pennatula* and *Gorgonia* occur in the Cretaceous and Tertiary rocks. *Heliopora*, which is closely allied to *Heliolites*, is first found in the Cretaceous.

Fossil corals are most abundant in calcareous rocks and comparatively rare in argillaceous and arenaceous beds, many limestone rocks being formed almost entirely of coral remains. This is indeed what might be expected, since existing forms can, as a general rule, live only in clear water.

The chief features in the geological distribution of the Actinozoa are given in the following table.

Cambrian. A few corals have been recorded from this system in North America and the south of Europe.

Ordovician. In North America corals are abundant in this system, but in England only a few forms have been found, the most important being *Favosites*, *Heliolites* and *Halysites*.

Silurian. Corals are very abundant, especially in the Wenlock limestone. *Cyathophyllum*, *Acervularia*, *Omphyma*, *Favosites*, *Heliolites*, *Halysites*.

Devonian. *Cyathophyllum*, *Acervularia*, *Phillipsastræa* (= *Smith-*), *Cystiphyllum*, *Calceola*, *Pachypora*, *Pleurodictyum*, *Heliolites*.

Carboniferous. *Cyathophyllum*, *Lithostrotion*, *Clisiophyllum*, *Lonsdaleia*, *Zaphrentis*, *Amplexus*, *Michelinia*, *Syringopora*.

Permian. Only a very few forms have been found.

Trias. Corals are absent in England, but abundant in the Alpine Trias; most of the Palæozoic forms have become extinct and we

find in place of them *Rhabdophyllia*, *Cladophyllia*, *Montlivaltia*, *Thecosmilia*, *Isastræa* and *Omphalophyllia*.

Jurassic. *Montlivaltia*, *Isastræa*, *Thamnastræa* and *Thecosmilia* are found in the Lias but are not common; in the Oolites they become very abundant and several other genera also occur.

Cretaceous. Corals are not abundant in England; the chief forms are *Parasmilia*, *Trochocyathus*, *Micrabacia* and *Holocystis*.

Cainozoic. Corals are rare in English Cainozoic formations. *Turbinolia*, *Dendrophyllia*, *Oculina* and *Litharæa* occur in the Eocene; *Madrepora* in the Oligocene; *Flabellum* in the Pliocene.

IV. ECHINODERMA.

Classes.	*Orders.*
1. Asteroidea.....	1. Encrinasteriæ. 2. Euasteriæ.
2. Ophiuroidea.	
3. Echinoidea.	1. Palæechinoidea. 2. Euechinoidea.
4. Holothuroidea.	
5. Crinoidea.	
6. Cystidea.	
7. Blastoidea.	

THE animals included in this division are all marine; they comprise the starfishes, brittle-stars, sea-urchins, sea-lilies, sea-cucumbers, and the extinct blastoids and cystideans. The body is very often radially symmetrical, the symmetry being generally pentamerous. But in many cases there is a more or less well-marked bilateral arrangement of parts. The echinoderms are never compound animals. In the majority of cases the alimentary cavity terminates in an anus. Part of the body-cavity (cœlom) forms what is known as the *water-vascular system*; this consists of a set of vessels containing a watery fluid and generally placed in communication with the sea-water by means of a canal; one vessel forms a ring round the œsophagus from which five radiating trunks are given off. The

water-vascular system functions generally in locomotion, and also in respiration. A nervous system is present and has a distribution similar to that of the water-vascular system. Reproduction is mainly sexual; as a rule the sexes are separate, but they do not differ externally.

In all the echinoderms there is a dermal skeleton. This is calcareous and consists sometimes of isolated pieces, but more usually of rods or plates, forming a complete exo-skeleton, which may be either flexible or rigid; spines

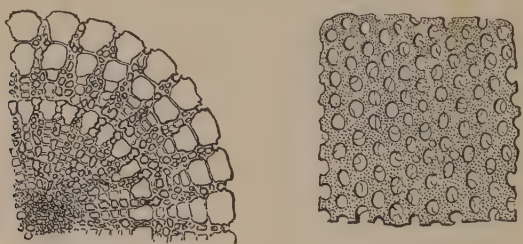


Fig. 26. *A*. Portion of transverse section of a spine of a sea-urchin *Echinometra*, Recent. Magnified. *B*. Section of interambulacral plate of recent *Cidaris* cut parallel to the surface. Magnified.

and other processes are often attached to the plates. When examined microscopically each part of the skeleton is found to be formed of a network of calcareous rods (fig. 26). The details of the structure vary in different forms, depending on the size and shape of the spaces between the rods. In the spines of the sea-urchins the network of rods is frequently arranged so as to form radiating perforated plates (fig. 26 *A*) which are united by rods placed at right angles to them. The axial portion of the spine often has a coarser and less regular structure than the other parts. Another characteristic feature of

the skeleton is that each component part shows the optical characters of a crystal of calcite, and differs only from an ordinary crystal in not having crystal contours and in the possession of the netted structure. In a plate the principal crystallographic axis is at right angles to the surface, in a spine it is parallel to the length. In fossil forms the spaces in the network of rods usually become filled with calcite, which is deposited in crystalline continuity with that forming the plate or spine. In such cases the characteristic cleavage of calcite becomes well marked, so that when the plate or spine is broken, the fracture passes along the cleavage planes, instead of being irregular as in the recent forms. By the infiltration of calcite and the development of cleavage, the organic structure in the fossils is sometimes more or less completely destroyed.

The Echinoderma are divided into seven classes:—(1) Asteroidea; (2) Ophiuroidea; (3) Echinoidea; (4) Holothuroidea; (5) Crinoidea; (6) Cystidea; (7) Blastoidea. The first four classes include the free forms and are often grouped together as the *Echinozoa*; the remaining three classes are known as the *Pelmatozoa*, the members of which are characterised by being attached during some part of their existence.

CLASS I. ASTEROIDEA.

In the Asteroids or starfishes the body is flexible; sometimes it is pentagonal in outline, but in the majority of cases it is more or less star-shaped, consisting of a central part, known as the *disc*, and of five *arms* or *rays*. In a few forms there are more than five arms, *e.g. Solaster papposus* which has thirteen.

The mouth and tube-feet are placed on the under surface of the animal. The mouth is in the centre of

the disc, and along the arms are rows of *tube-feet*; these are tubular processes connected with the radial water-vascular vessel. This surface then may be called the *oral, ambulacral,* or *ventral* surface. The upper surface is *aboral, anti-ambulacral,* or *dorsal*; on it occurs the anus placed near the centre of the disc. In some forms the anus is absent. On the dorsal surface between two of the rays is a porous plate, the *madreporic plate*; sometimes more than one is present.

On the ventral surface of each arm, there is a deep longitudinal groove, the *ambulacral groove*; this is formed by two rows of plates known as the *ambulacral ossicles,* (fig. 27 *a*) which are in contact dorsally; the ossicles on opposite sides of the groove are movably articulated. Along each side of the ambulacral groove, there is a row of pores, each pore being between two ossicles; generally the pores are arranged in a straight line, but in some forms they are zigzag, being alternately near to, and distant from, the middle of the ambulacral groove. External to the rows of ambulacral ossicles there is on each side of the groove, another row of plates, the *ad-ambulacral plates* (*b*). At the sides of the arms there are in many cases two rows of *marginal plates* (*c, d*)—the *superior-* and *inferior-marginals.* The dorsal surface of the skeleton is formed of a meshwork of calcareous rods with membranous inter-spaces, but in a few forms distinct plates are present on the disc. Short spines are often abundant. Pedicellariæ are also of fre-

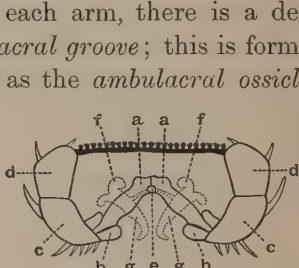


Fig. 27. Section of the arm of a star-fish (*Astropecten*). *a*, ambulacral ossicles; *b*, ad-ambulacral plates; *c*, inferior-marginal plates with spines; *d*, superior-marginals; *e*, radial water vessel; *f*, ampulla; *g*, tube-feet. Enlarged.

quent occurrence, especially on the dorsal surface; they are modified spines consisting typically of two movable blades which are often borne on a stalk, and probably serve to remove foreign bodies from the surface of the animal. Projecting into the mouth at the angles formed by the ambulacral grooves are five pairs of plates, which give the mouth a star-shaped form. The mouth leads into the globular stomach, which passes into the pentagonal pyloric sac, from the angles of which processes are given off, and pass into the arms near the aboral surface. From the pyloric sac a short narrow intestine leads to the anus. The water-vascular system consists of a vessel forming a ring round the mouth (fig. 28 *a*), from which a branch (*b*) is given off down each arm, and is placed in the ambulacral groove outside the skeleton. Each of these radial vessels gives off two rows of processes on opposite sides, which pass through the pores between the ambulacral ossicles into vesicles situated dorsally to the ossicles and known as the *ampullæ* (*g*), and also into the tubular processes known as the *tube-feet* (*f*), which project along the ventral surface of the arm and are provided at their extremities with sucking discs. It is by means of the tube-feet that the animal moves. The ampullæ contract, forcing water

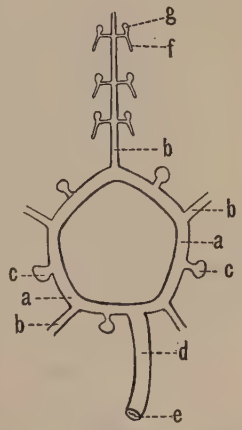


Fig. 28. Diagram of the water-vascular system of a star-fish. *a*, circular vessel round the mouth; *b*, radial vessels; *c*, Polian vesicles; *d*, stone-canal; *e*, madreporic plate; *f*, tube-feet (only a few shown); *g*, ampulla.

into the tube-feet, which then expand and become attached to some foreign object; afterwards the ampullæ become distended causing the tube-feet to contract. The water-vascular system is placed in communication with the sea-water by means of a canal (fig. 28 *d*) passing from the circular vessel to the dorsal surface of the disc and ending in the madreporic plate. This is known as the *stone-canal* on account of the deposit of carbonate of lime in its walls.

The distribution of the main part of the nervous system is similar to that of the water-vascular system. It consists of a ring round the mouth and of a branch which goes down the ambulacral groove of each arm; there is also a radial nerve along the dorsal surface of each arm. The genital glands occur in pairs at the base of each arm and they open to the exterior between the rays on the dorsal surface.

ORDER I. ENCRINASTERIÆ.

The ambulacral ossicles alternate on either side of the ambulacral groove.

Palæaster. Arms five, thick, convex, short or of moderate length. The dorsal surface formed of rows of small ossicles provided with spines. There is a row of ad-ambulacral plates and also a row of large marginal plates. Madreporic plate small. Bala Beds to Carboniferous. Ex. *P. eucharis*, Devonian.

ORDER II. EUASTERIÆ.

The ambulacral plates are placed opposite each other.

Metopaster. Body flattened, pentagonal in outline, the rays only slightly produced. Marginal plates thick,

covered with punctations and surrounded by a depressed border. Superior-marginal plates few in number, forming a broad border to the disc; the terminal pair of plates the largest. Dorsal surface covered with small polygonal (usually hexagonal) plates. Inferior-marginal plates more numerous than the superior-marginals. Plates on the ventral surface small, polygonal. Cretaceous. Ex. *M. parkinsoni*[1], Upper Chalk.

Distribution of the Asteroidea.

The Asteroidea have a wide distribution in the ocean at the present day; they are most abundant at moderate depths, but also occur in abyssal regions.

The fossil forms do not differ greatly from the modern ones. The Encrinasteriæ are confined to the Palæozoic formations. A few Euasteriæ occur in the Palæozoic, but they are mainly Neozoic forms. The earliest star-fishes are found in the Bala Beds, where we get the genus *Palæaster*. They are more abundant in the Silurian, where *Palæaster*, *Palæasterina*, and *Palæocoma* occur. *Palæaster* and others are found in the Devonian. The Jurassic forms have been referred to the genera *Solaster*, *Astropecten*, and *Plumaster*. *Metopaster* is common in the Upper Cretaceous. In the Cainozoic rocks star-fishes are rare.

CLASS II. OPHIUROIDEA.

In the Ophiuroids or brittle-stars, the body consists of a disc and arms. The arms are generally five in number, usually simple, but in some cases branched; they

[1] In most works this species is referred either to *Goniaster* or *Goniodiscus*.

are much smaller than in the star-fishes and are merely appendages of the disc and not prolongations. Usually they are long, cylindrical, and very flexible, serving for locomotion by means of movements which take place chiefly in a horizontal direction. Unlike the arms of the star-fish they do not contain any prolongations of the alimentary canal, and the ambulacral groove is not open to the exterior. The arrangement of the nervous and the water-vascular systems is similar to that found in the Asteroidea; but the tube-feet are not provided with sucking-discs and there are no ampullæ. The madreporic plate is on the ventral surface. There is no anus, and pedicellariæ are nearly always absent.

Generally there is a well-developed skeleton. In a typical case the following parts are found. Encasing the arms, there are four rows of plates (fig. 29), one dorsal, one ventral, and two lateral. The lateral are provided with rows of spines. Between the lateral and the ventral plates are apertures for the passage of the tube-feet. The greater part of the space enclosed by the four rows of plates is filled up by a longitudinal row of ossicles (*d*); each ossicle consists of two parts which are nearly always fused together along the median vertical line. Each ossicle in the row articulates with the preceding and succeeding one, so that the arm is flexible. On the ventral surface of the row there is a groove (*e*) in which the water-vascular vessel and the nerve cord are placed

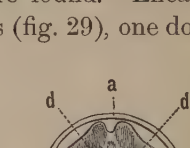


Fig. 29. Section of the arm of an Ophiuroid (*Ophioglypha*). *a*, dorsal plate; *b*, lateral plate; *c*, ventral plate; *d*, ambulacral ossicles fused along the median vertical line; *e*, ambulacral groove. Enlarged.

this corresponds to the ambulacral groove of the star-fish, and the plates above to the ambulacral ossicles.

The disc is usually round or pentagonal. On its ventral surface (fig. 30 *A*) the arms are prolonged so as to reach the mouth. The last pair of ambulacral ossicles,—those next the mouth, instead of being fused like the others, become free, and each ossicle unites with that of the adjoining arm. The parts of the disc between the arms are known as the *interbrachial areas*; these are covered mainly with scaly plates and granules, but in each of the areas there is one large plate, the *buccal plate* (*b*), and other smaller plates, projecting into the mouth, giving it a stellate form. One of the buccal plates serves as the madreporic plate. The genital openings (*g*) also occur on the ventral surface of the disc; they are in the form of slits in the interbrachial areas, usually two in each, situated near the bases of the arms; occasionally there are four. The dorsal surface of the disc (fig. 30 *B*) is, in most cases,

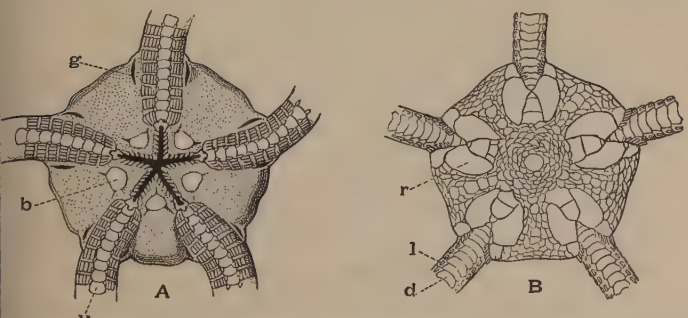


Fig. 30. *A. Ophiura*, Recent. Ventral surface of disc and part of the arms. *b*, buccal plates; *g*, genital slits; *v*, ventral plates of arms. *B. Ophioglypha*, Recent. Dorsal surface. *r*, radial plates; *l*, lateral plates of arms; *d*, dorsal plates of arms. $\times 1\frac{1}{2}$.

covered with numerous small plates; but usually there is

at the bases of the arms on each side, a large plate, the *radial plate* (*r*); on this surface the arms end abruptly at the margin of the disc.

Distribution of the Ophiuroidea.

The majority of the Ophiuroids at the present day live in shallow water, more than half of the known species being found above a depth of 30 fathoms, and most of these not extending lower. Other forms occur at greater depths, as many as 69 species being found below 1000 fathoms. Ophiuroids are rare as fossils; the earliest form occurs in the Bala Beds, and belongs to the genus *Protaster*; this genus ranges on to the Silurian, where *Eucladia* and others appear. In the Mesozoic we get *Geocoma*, and forms which have been referred to the existing genera *Ophiura*, *Ophiolepis* and *Ophiocten*. A few occur in the Eocene.

CLASS III. ECHINOIDEA.

The Echinoids or sea-urchins have usually a globular, heart-shaped, or discoidal body. The shell or test consists of numerous calcareous plates, which, in the majority of cases, are immovably united. There is nothing corresponding to the ambulacral groove of the star-fish, the water-vascular system being internal, and as a result the tube-feet in order to reach the exterior, must pierce the plates of the test. The mouth is always on the inferior surface; it is often central, but when excentral is placed anteriorly. The anus is either at the summit of the test or posterior to it, somewhere along a line drawn from the summit to the mouth. In the test we may distinguish

three parts, a small patch of plates placed at the summit, known as the *apical disc*, a series of the plates surrounding the mouth, and the remainder of the test termed the *corona*.

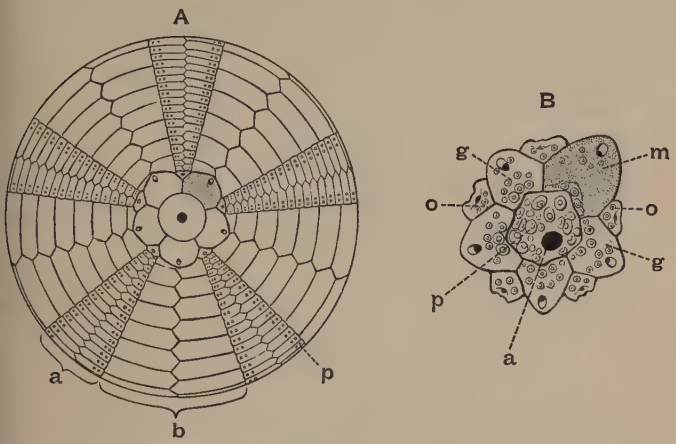


Fig. 31. *A*. Diagram of the upper surface of a regular echinoid, with the tubercles and spines omitted. *a*, ambulacral areas; *b*, inter-ambulacral areas; *p*, pores in the ambulacral plates.

B. Apical disc of *Echinus esculentus*, Recent. *a*, anus; *p*, periproct; *g*, genital plates, each with a pore; *m*, madreporic plate; *o*, ocular plates. Enlarged.

In a typical echinoid of the regular group (*e.g. Echinus*) the anus is placed within the apical disc (fig. 31 *B*), which then consists of the following parts. Near the centre is the anus (*a*), which is surrounded by a membrane covered with scaly plates and known as the *periproct* (*p*). The periproct is encircled by a ring formed of ten plates, five are called *genital* (*g*) and five *ocular* (*o*). The genital plates form the inner part of the ring; they are often more or less hexagonal in outline, and are usually provided with a pore which serves as the opening for the genital ducts—

whence their name. In some cases one or more of the plates is imperforate; one has a porous structure and serves as the madreporic plate (*m*). Outside the genital plates and alternating with them are the ocular plates; these are smaller than the genital and usually triangular or pentagonal and each has a perforation for what has been regarded as the eye-spot[1]. In the irregular echinoids (*e.g. Micraster*, figs. 35, 36), the anus is not placed within the apical disc, which is then smaller. In *Echinocorys*

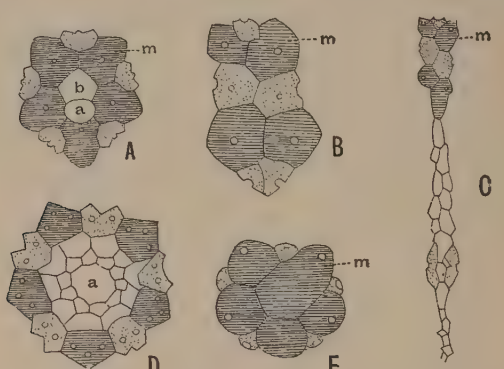


Fig. 32. Some types of Apical Disc. *A*. *Peltastes wrighti*, Lower Greensand. *B*. *Echinocorys vulgaris*, Upper Chalk. *C*. *Collyrites bicordata*, Inferior Oolite. *D*. *Palæechinus* Carboniferous Limestone. *E*. *Echinoconus subrotundus*, Chalk. In the figures the ocular plates are distinguished by dots, the genital plates by lines. *m*, madreporic plate; *a*, anus; *b*, sur-anal plate. All enlarged.

(fig. 32 *B*) the anterior genital plates are separated from the posterior by two oculars; in *Collyrites* (*C*) the apical disc is still more elongated. In *Salenia* and allied forms

[1] The genital plates are sometimes termed *basals* and the oculars are also known as *radials*, since they have been considered to represent the plates which bear the same names in other groups of the Echinoderma.

(*A*) there is an extra plate (*b*) at the centre of the disc known as the sur-anal or dorso-central plate.

The corona consists of twenty rows of plates, each row extending from the apical disc to near the mouth. The plates are of two kinds, *ambulacral* (fig. 31 *A*, *a*) and *interambulacral* (*b*); they are arranged in pairs, there being five double rows of ambulacrals separated by five double rows of interambulacrals; each double row is termed an *area*. The former end against the ocular plates, the latter against the genital, and in each case fresh plates are developed next the apical disc. In each area the plates alternate on either side, and since their inner ends are angular, the line between the two rows is zig-zag. The ambulacral plates are smaller and more numerous than the interambulacral, and they are perforated by pores (*p*) for the passage of the tube-feet to the exterior, a radial water-vessel being placed under each ambulacral area. The pores may be round or elongated; they are situated in the outer portion of the plates and are almost always in pairs; sometimes there is one pair on each plate, sometimes more. When there is one pair, the pores are said to be *unigeminal*, two pairs *bigeminal*, three pairs *trigeminal*. When more than one pair of pores are found on each plate (fig. 33), a careful examination shows that the plate is compound and really consists of several small plates which have become fused together, each pair of pores marking an original plate; this fusion is due to growth-pressure—since each plate of the test is enlarging and new

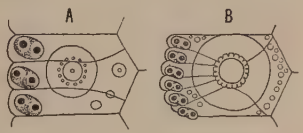


Fig. 33. Compound Ambulacral Plates. *A*. *Diadema hemisphæricum*, from the Corallian, formed of three fused plates. *B*. *Cyphosoma königi*, from the Chalk, formed of six fused plates. Enlarged.

plates are being added next the apical disc. Some of the original plates may, on fusing, become reduced in size owing to absorption of material. Sometimes the pores in each pair are united by a groove, and are then termed *conjugate*. In some sea-urchins the rows of pores extend from the apical disc to the mouth without any important alteration; the ambulacral areas are then said to be *simple* (*e.g. Cidaris*). In others the two rows of pores in each ambulacral area diverge soon after leaving the apical disc, and then come together again before reaching the equator, so that the five ambulacra form a rosette on the upper surface of the corona, the pores being but irregularly developed on the lower surface; the ambulacral areas are then termed *petaloid* (*e.g. Scutella*), and when the rows of pores diverge but do not come in contact at their lower ends they are *sub-petaloid* (*e.g. Echinobrissus*).

The plates of both the ambulacral and interambulacral areas are often provided with rounded elevations known as *tubercles* and *granules*. The tubercles are of various sizes, the largest being the primary. In these the following parts may be distinguished; at the summit there is a spheroidal piece, which is sometimes perforated, and is known as the *mamelon* (fig. 34 *B*, *m*). The mamelon rests on a short pillar termed the *boss* (*b*), the upper margin of which is sometimes smooth, sometimes crenulated. The

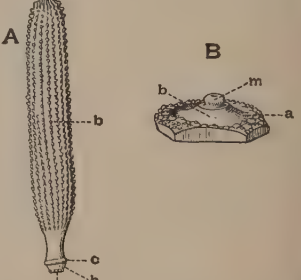


Fig. 34. *A*. Spine of *Cidaris florigemma*, from the Corallian Rocks. *a*, acetabulum; *h*, head; *c*, collar; *b*, body or stem. *B*. Ambulacral plate of *Cidaris* (recent) with a large primary tubercle and secondary tubercles. In the primary tubercle, *m*, mamelon; *b*, boss; *a*, areola. Natural size.

base of the boss is frequently surrounded by a smooth excavated space, the *areola* (*a*). The granules are smaller than tubercles.

Attached to the tubercles are the *spines*; these are of different sizes and shapes in different genera and species, and even on the same individual, being needle-like, rod-like, or flask-shaped. At the end of the spine where it articulates with the mamelon there is a rounded cavity, the *acetabulum* (fig. 34 *A*, *a*), next comes the *head* (*h*) limited above by a ring or collar (*c*) which may be smooth or crenulate and serves for the attachment of the muscles that move the spine. Beyond the collar and forming the greater part of the spine is the *stem* or body (*b*), which may be smooth, or ornamented with ridges or rows of spiny processes. Pedicellariæ, which are stalked and usually provided with three blades, also occur.

On the surface of some sea-urchins, there are bands covered with very minute tubercles, which in the living state bear slender modified spines; these bands are termed *fascioles*, sometimes they form a ring beneath the anus (*e.g. Micraster*, fig. 35 *c*) when they are said to be *sub-anal*, in other cases they encircle the rosette formed by the petaloid ambulacra (*e.g. Hemiaster*) and are said to be *peripetalous*.

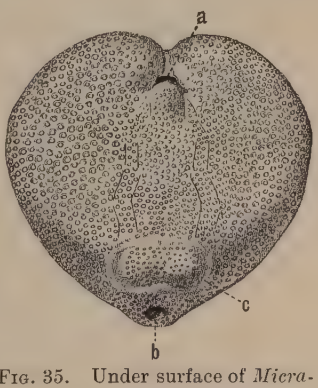


FIG. 35. Under surface of *Micraster cor-anguinum* from the Upper Chalk, showing fasciole. *a*, peristome; *b*, periproct; *c*, fasciole. One-half natural size.

The mouth is placed in the centre of a membrane,

which is covered with plates or granules, and is known as the *peristome*. This is usually lost in fossil specimens, and consequently the aperture which is found does not represent the mouth only, but the peristome. The shape of the peristome varies in different genera, it may be circular, oval, pentagonal, or decagonal. At the commencement of the alimentary canal there is in some genera a complicated calcareous apparatus which functions in mastication; this is composed of numerous pieces, and is connected with internal processes at the margin of the peristome which are often in the form of arches, known as *auricles*.

In the irregular echinoids there is a well-marked bilateral symmetry; a plane which passes through the anus (which is in the posterior interambulacral area), the apical disc, and the mouth, divides the body into two similar parts. The ambulacra are often markedly dissimilar, the anterior one differing from the others which are paired. The bilateral character is less conspicuous in the regular sea-urchins, but the plane of symmetry may be found by means of the madreporic plate, which is always placed at the upper end of the right anterior interambulacral area.

The Echinoidea are divided into two Orders based mainly on the number of rows of plates in the areas:—(1) the Palæechinoidea, (2) the Euechinoidea.

ORDER I. PALÆECHINOIDEA.

The number of rows of plates forming the test varies; in each interambulacral area there is either one[1], or more

[1] *Bothriocidaris* is the only known genus of echinoid which possesses a single row of plates in each interambulacral area.

than two; in each ambulacral two or many. The plates frequently overlap, giving the test a certain amount of flexibility. All the genera, except *Echinocystites*, are regular. In the genital plates there are from three to five pores, in the oculars two or none. Jaws are present.

Palæechinus (fig. 32 *D*). Test spheroidal, rigid. Apical disc central, enclosing the anus. Five large genital plates, each with three perforations,—but in some cases one of the genitals may have a single perforation. Ocular plates five, small, each with two perforations. Ambulacral areas narrow, straight, with two rows of plates, pores unigeminal, each pore divided by a septum. Interambulacral areas wide, with four to eight rows of plates at the equator, fewer towards the poles; plates hexagonal, except those next the ambulacral area, which are pentagonal; surface of plates covered with granules. Spines small. Upper Silurian to Carboniferous Limestone. Ex. *P. intermedius*, Carboniferous.

Archæocidaris. Test large. Ambulacral areas narrow, formed of two rows of plates; pores unigeminal. Interambulacral areas consist of from three to five rows of large plates, the middle ones being hexagonal; each plate has a large primary perforated tubercle which bears a long spine. Carboniferous Limestone. Ex. *A. urii.*

ORDER II. EUECHINOIDEA.

The test is always formed of twenty rows of plates, two in each area. The plates very rarely overlap. Regular and irregular forms occur. There is usually one pore only in each genital and ocular plate. Jaws are present in some forms, but absent in others.

(*a*) *Regular Euechinoids.*

The test is radially symmetrical and generally spheroidal. The apical disc encloses the anus. The mouth is central. The ambulacral areas are simple. Jaws are present.

Cidaris. Test spheroidal, the summit and base equally flattened. Apical disc very large, rarely preserved fossil, ocular plates large. Ambulacral areas narrow, undulating, pores unigeminal; between the rows of pores are vertical rows of small tubercles and granules. Interambulacral areas wide, plates large, each with a primary tubercle which is perforated, and may be crenulated or smooth; areola large, surrounded by secondary tubercles, beyond which are granules. Peristome rounded. Spines large, of various forms, generally ornamented with rows of granules. Trias to present day. Ex. *C. florigemma*, Corallian, and Kimeridge Clay.

Peltastes (fig. 32 *A*). Test circular in outline, depressed. Apical disc very large, prominent, containing one extra plate, the sur-anal (or dorso-central), placed in front of the periproct; the madreporic plate has an oblique fissure. Ambulacral areas narrow, straight or slightly flexuous, with small tubercles; pores unigeminal except near the mouth. Interambulacral areas wide, with large primary tubercles, which are imperforate, but may be crenulate. Peristome slightly notched. Upper Jurassic to Gault. Ex. *P. wrighti*, Lower Greensand.

Salenia. Similar to *Peltastes*, but the periproct is placed to the right of a line drawn from the anterior to the posterior margin. Cretaceous to present day. Ex. *S. petalifera*, Upper Greensand.

Acrosalenia. Form similar to *Peltastes*. Apical disc rather large; genital plates large, the posterior smaller than the others and differing in shape. A sur-anal plate in front of the periproct which is in the antero-posterior line. Pores unigeminal except near the peristome. Interambulacral areas with large perforate tubercles. Spines smooth or striated. Lias to Cretaceous. Ex. *A. spinosa*, Inferior Oolite to Corallian.

Hemicidaris. Test spheroidal, inferior surface flattened. Apical disc small. Ambulacral areas narrow, slightly flexuous, with two rows of tubercles on the under surface, which pass into granules on the upper. Pores unigeminal, but bigeminal or trigeminal near the peristome. Interambulacral areas broad; plates large and few, each with a large perforated and crenulated tubercle, and also smaller tubercles and granules. Spines cylindrical, long. Peristome large, decagonal. Inferior Oolite to Cretaceous. Ex. *H. intermedia*, Corallian.

Diadema (= *Pseudodiadema*[1]) (fig. 33 *A*). Test circular or slightly polygonal, depressed. Apical disc and periproct large. Ambulacral areas straight, narrower than the interambulacra, with two rows of tubercles; plates compound, usually with three pairs of pores on each plate. Interambulacral areas with two or more rows of primary perforate tubercles. Peristome large, decagonal. Lias to present day. Ex. *P. ornatum*, Lower Chalk.

Cyphosoma (fig. 33 *B*). Form similar to *Diadema*. Ambulacral plates compound, each may consist of four, five, or six united plates with the same number of pairs of pores; two rows of primary tubercles. Interambulacral

[1] According to Duncan this genus does not differ from *Diadema* (Recent).

areas with two or more rows of primary imperforate tubercles. Jurassic to Eocene; common in the Chalk Ex. *C. königi*, Upper Chalk.

(*b*) *Irregular Euechinoids.*

The test is bilaterally symmetrical. The anus i placed outside the apical disc. The mouth is central o excentral. Ambulacra simple or petaloid. Jaws may b present or absent.

Echinoconus (= *Galerites*) (fig. 32 *E*). Test conica or almost hemispherical, inferior surface flat, outlin pentagonal or oval. Apical disc small. Ambulacra areas narrow, straight, simple; pores unigeminal, bu trigeminal near the mouth. Interambulacral areas wit broad plates, tubercles very small, perforated and crenu lated. Peristome small, central, decagonal. Jaws absen Periproct marginal or sub-marginal. Upper Greensan to Upper Chalk. Ex. *E. conicus*, Upper Chalk.

Holectypus. Test hemispherical, depressed, bas excavated. Apical disc small. Ambulacral areas narrow straight, simple; pores unigeminal, tubercles small. In terambulacral areas with rather large plates, tubercle small. Peristome central, decagonal. Jaws presen Periproct large, placed between the peristome and th posterior margin of the test. Inferior Oolite to Coralliar also foreign Cretaceous. Ex. *H. hemisphericus*, Inferi Oolite.

Discoidea. Form similar to *Holectypus*. In th interior are ten vertical plates extending from the margi of the test towards the mouth, and placed on each side

the ambulacral areas. Cretaceous. Ex. *D. cylindrica*, Chalk.

Pygaster. Test large, depressed, outline pentagonal or circular, base concave. Apical disc small, madreporic plate large. Ambulacral areas straight, simple; pores unigeminal; tubercles in vertical rows. Interambulacral areas wide, tubercles perforate. Peristome central, large, decagonal. Jaws present. Periproct very large, placed behind the apical disc. Inferior Oolite to Cretaceous. Ex. *P. umbrella*, Corallian.

Echinobrissus (= *Nucleolites*). Test depressed; outline oval or quadrilateral, rounded anteriorly, truncated and broadest posteriorly; inferior surface concave. Apical disc compact, four perforate genital plates, and one imperforate. Ambulacral areas sub-petaloid, pores unigeminal, the outer pore elongated. Interambulacral plates wide, tubercles small. Peristome oval or pentagonal, excentric, a little anterior. Jaws absent. Periproct placed in a sulcus on the dorsal surface. Inferior Oolite to Recent. Ex. *E. scutatus*, Corallian.

Collyrites (fig. 32 *C*). Test ovoid, inflated. Apical disc greatly elongated; at the anterior end are four perforated genital plates separated by two oculars, at the other end are two oculars; these two groups of plates are connected by numerous small plates. Ambulacral areas simple, pores unigeminal. The three anterior ambulacra meet at the anterior end of the apical disc, the other two meet at the posterior end. Interambulacral areas broad, tubercles small. Peristome excentral. Periproct above the posterior margin. Inferior Oolite to Cretaceous. Ex. *C. bicordata*, Corallian.

Echinocorys (=*Ananchytes*) (fig. 32 *B*). Test very

convex above, inferior surface flattened, outline oval. Apical disc a little elongated; the four genital plates perforated, the two anterior separated from the two posterior by two ocular plates. Ambulacral areas simple, pores unigeminal. Interambulacral plates large, tubercles small. Peristome anterior. Jaws absent. Periproct oval, inframarginal. Upper Chalk. Ex. *E. vulgaris.*

Holaster. Test heart-shaped, inferior surface more or less flattened, superior surface with a broad shallow groove anteriorly. Apical disc elongate, the two pairs of genital plates separated by two oculars. Ambulacral areas large, simple; pores unigeminal, round or elongate, the anterior ambulacrum in the groove. Interambulacral areas with small tubercles and granules. Peristome excentric and elliptical. Jaws absent. Periproct supramarginal. Upper Greensand and Chalk; also Tertiary in Australia. Ex. *H. subglobosus*, Lower Chalk.

Micraster. (figs. 35, 36). Test heart-shaped or oval. Apical disc small, excentric. Ambulacral areas sub-petaloid, placed in sunken areas, the sub-petaloid part of the two anterior-lateral longer than that of the two posterior-lateral; pores unigeminal. The anterior unpaired ambulacrum in a deep groove, with its pores circular. Interambulacral areas with large plates; tubercles small, perforate and crenulate. A fasciole placed below the anus. Peristome excentral, near the anterior border,

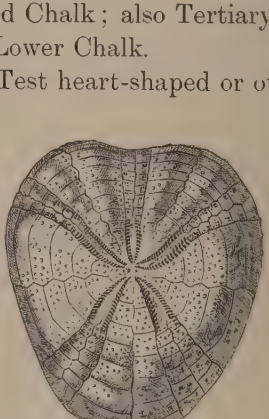


Fig. 36. *Micraster cor-bovis*, an Irregular Euechinoid, from the Upper Chalk. One-half natural size.

with a projecting lip. Jaws present. Periproct supramarginal. Chalk Rock and Upper Chalk; also Tertiary in Australia. Ex. *M. cor-anguinum*, Upper Chalk.

Distribution of the Echinoidea.

Some Echinoids live at great depths in the ocean, no less than a dozen species having been found below the 2000 fathom line, and one even at 2900 fathoms; but by far the larger number occur near the coasts in shallow water; thus of the 297 existing species recorded by Agassiz, 201 are found in water of less than 150 fathoms in depth. Echinoids are most abundant where the sea-bottom is rocky, sandy, or calcareous, and less common where it is muddy; consequently fossil forms are rare in clayey strata. Those found in deep water have a much wider range in space than those found in shallow water. Many genera, especially those with a considerable range in depth, have also a long range in time, some extending back to the Cretaceous period and even earlier. Amongst the forms found in the Cretaceous which are still existing in deep water may be mentioned *Salenia*, *Cottaldia*, *Hemiaster*, and *Pygaster*.

There is a marked contrast in the distribution of the two Orders of the Echinoidea. The Palæechinoids are found almost exclusively in the Palæozoic, only one genus occurring in the Mesozoic, namely *Tiarechinus* from the Trias[1]. The Euechinoids are nearly confined to the Neozoic, *Eocidaris* from the Permian, being the only genus found in the Palæozoic.

[1] *Tetracidaris*, from the Cretaceous, is by some authors referred to the Palæechinoidea; it has four rows of plates in each interambulacral area, but appears to be more closely allied to *Cidaris* than to any Palæechinoid.

The earliest echinoid belongs to the genus *Bothriocidaris* and was found in the Ordovician rocks of Esthonia in Russia. In the Silurian we get *Palæechinus* and *Echinocystites*; in the Devonian, *Lepidocentrus*; in the Carboniferous, *Palæechinus, Melonites,* and *Archæocidaris*. *Cidaris* is the chief form in the Trias. In the Jurassic the echinoids are much more numerous, relatively to the other groups of animals, than in the earlier formations; they are rare in the Lias and the other clayey divisions, but very abundant in the calcareous beds, especially in the Inferior Oolite and Coral Rag. The genera which are best represented in the Jurassic are, of the regular group, *Cidaris, Hemicidaris, Acrosalenia, Diadema,* and *Stomechinus*; of the irregular group, *Collyrites, Echinobrissus, Holectypus,* and *Pygaster*. In the Cretaceous the echinoids are even more abundant than in the Jurassic; many of the genera found in the Lower Cretaceous occur also in the Upper Jurassic. The most important genera are, (1) regular, *Cidaris, Diadema, Cyphosoma, Peltastes, Salenia,* (2) irregular, *Discoidea, Echinoconus* (= *Galerites*), *Hemiaster, Micraster, Cardiaster, Holaster, Echinocorys,* (= *Ananchytes*). Between the Cretaceous and the Eocene there is, in Britain, an enormous break in the succession of the echinoids, not a single species being common to the two systems, and the genera are mostly different. This change is due in part to the great difference in the conditions under which the deposits were formed, the Chalk being a comparatively deep water formation, and the Eocene beds, shallow water; but the Eocene forms differ much more from those of the Upper Chalk than from those of the Chalk Marl, the latter having been formed in water of less depth. Throughout the English Tertiaries the echinoids are much rarer

than in the Cretaceous; thus in the Cretaceous there are thirty genera, in the Eocene seven, in the Pliocene eleven. In the Eocene this can be accounted for largely by the fact that the sea-bottom was for the most part muddy; in the Pliocene by the lower temperature of the ocean. The London Clay echinoids belong to tropical or sub-tropical genera. The commonest Eocene forms are *Hemiaster* and *Schizaster*. The Pliocene forms present a considerable affinity to those now living in the West Indian seas, probably indicating the existence of shallow water between Europe and America in which migration could take place. The most important genera in the Pliocene are *Echinus*, *Echinocyamus*, *Spatangus*, and *Temnechinus*.

CLASS IV. HOLOTHUROIDEA.

This Class includes the sea-cucumbers. They possess an elongated and usually cylindrical body provided with a circle of tentacles around the mouth. From the water-vascular ring five radial vessels are given off, and branches also go to the tentacles. In *Synapta* and its allies, tube-feet, as well as the radial vessels, are absent. The stone-canal in almost all cases opens into the body-cavity. The integument is leathery, and the skeleton is very poorly developed, consisting of minute isolated pieces of various shapes, such as spicules, anchors, and wheels (fig. 37). At the present day the Holothurians are widely distributed, but owing to the nature of their hard parts they are

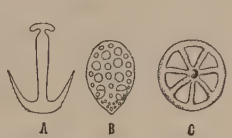


Fig. 37. A, B, Anchor and plate of *Synapta tenera*, Recent. C, wheel of *Chirodota convexa* from the Inferior Oolite. Enlarged.

136716

rarely found fossil. The earliest forms occur in the Carboniferous rocks of Scotland, and a few have also been recorded from the Jurassic and later formations.

CLASS V. CRINOIDEA.

The Crinoidea or sea-lilies differ from the preceding groups in having the oral surface directed upwards and the dorsal surface downwards. In very many forms the animal is fixed by means of a stem given off from the dorsal surface, but in others this is the case only in the young state,[1] the adult form being free. The skeleton consists of a *stem*, and of a *calyx* formed of calcareous plates closely united and arranged in a regular manner; from the margin of the latter the *arms* are given off.

The visceral mass is placed in the calyx, which is more or less cup- or basin-shaped; the mouth in nearly all forms is either at or near the centre of the ventral surface, and the anus is excentral and usually at the end of a tubular process. On the oral surface of the visceral mass there are calcareous plates or isolated granules; in some forms there are five large plates—the *oral plates*, in others the plates are more numerous and may or may not be firmly joined together. In many forms there is on each side of the arms a row of small appendages,—the *pinnules*, which have the same structure as the arms. Usually there is a groove on the ventral surface of each arm and of each pinnule, and these grooves are continued to the mouth; they are lined with cilia, by the movements of which food is conveyed to the mouth. The arms are often numerous owing to repeated branching. Imme-

[1] There is no evidence to shew that *Marsupites* possessed a stem even in the young state.

diately under the groove of each arm there is a radial nerve cord; these cords unite to form larger trunks and ultimately join as a ring round the mouth. In addition to the nervous system already mentioned, there is another placed dorsally in the lower part of the calyx, sometimes in the centro-dorsal plate (*i.e.* one of the stem-joints which in some forms has become incorporated into the calyx), or between the basal plates; from this centre cords are given off, which pass through canals in the plates of the calyx to the arms and pinnules, and also into the stem when present. The water-vascular system consists of radial vessels and of a ring round the mouth; from this ring tubes hang down and open into the body-cavity, which communicates with the water of the exterior by means of pores. In connection with the radial vessels are tubular processes, the tentacles, which form a row on each side of the food-grooves, and correspond with the tube-feet of the star-fish, but do not function in locomotion.

In the majority of crinoids a stem is present (fig. 38 *a*); this is more or less flexible and is sometimes several feet in length. It is formed of a number of joints or segments which may be in the form of circular or pentagonal (occasionally elliptical) plates, or they may be much thicker than broad; but in all cases the joints are articulated by their flat surfaces. Each joint is pierced in the centre by a canal which is circular or pentagonal and contains a prolongation of the dorsal nervous system. The articular faces of the plates are often provided with radiating striæ or with ridges in the form of a rosette. From the stem small branches known as *cirri* are sometimes given off; these have a structure similar to that of the stem and are also pierced by a central canal. The

inferior part of the stem often expands and branches in a root-like manner, and serves to fix the animal. Sometimes the plates near the top of the stem become very much larger than the others.

The calyx consists at its base of a cycle of five (sometimes fewer) plates, known as the *basals* (fig. 38, *c*; 39 *b*). In some forms there is below the basals and alternating with them another row of plates, termed the *infra-basals* (fig. 38 *b*), and the base is then said to be *dicyclic*; when basals only are present, it is *monocyclic*. Above the basals and alternating with them, is a cycle of five *radial* plates (fig. 38 *d*; fig. 39 *r* 1). In some genera there are, between the rows of radials, other plates, the *inter-radials* (fig. 39 *a*); the arms arise from the radials; they have a groove on their upper surface, and are formed either of a single or of a double row of plates, the *brachials*; when double, the plates alternate with one another. The pinnules also consist of calcareous plates, with an arrangement similar to those of the arms. In many cases the groove on the arms is covered over by a series of plates. In some forms the earlier rows of brachial plates become firmly united (fig. 40 *r* 2, *r* 3); these fixed brachials have often been regarded as radials, but morphologically they are only brachials which have become incorporated into

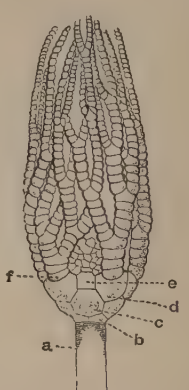


Fig. 38. *Cyathocrinus longimanus*, from the Silurian. *a*, portion of stem; *b*, infra-basal plates; *c*, basals; *d*, radials; *e*, anal inter-radial; *f*, first brachial. Reduced.

the calyx. The fixed brachials may be in contact at the sides or they may be separated by other plates which are termed *inter-brachials* (fig. 39 *ir*). In the posterior inter-radial area (that which leads up to the anus) the inter-brachial plates are often more numerous than in the other areas. Other plates, as mentioned above, occur on the ventral surface of the calyx.

Cyathocrinus (fig. 38). Calyx cup-like; dicyclic. Infra-basals five, small, pentagonal. Basals five, large, hexagonal (except the posterior, which is heptagonal and supports the inter-radial plate). Radials five. Arms five, very long, bifurcating several times, without pinnules. Oral plates five, large. Stem round. Silurian to Permian. Ex. *C. longimanus, C. acinotubus,* Silurian.

Actinocrinus (fig. 39). Calyx variable in form, pear-shaped, ovoid, or more or less spherical; monocyclic.

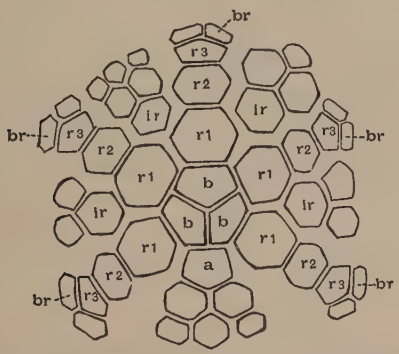


Fig. 39. Diagram of the plates of *Actinocrinus triacontadactylus*, Carboniferous Limestone. *b*, basal plates; *r* 1, radials; *r* 2, *r* 3, fixed brachials; *br*, brachial plates; *ir*, inter-brachials; *a*, inter-radial.

Basals three, forming a hexagon. Radials five, high. The first two rows of brachials firmly united. Inter-

brachials present; and also one (posterior) inter-radial above which the inter-brachials are more numerous than in the other areas. The ventral surface covered with thick, tubercled, hexagonal plates; anus sometimes at the end of a process. Arms ten to thirty, with two rows of plates. Stem circular, canal pentagonal. Silurian to Carboniferous Limestone. Ex. *A. triacontadactylus*, Carboniferous Limestone.

Crotalocrinus. Calyx dicyclic. Infra-basals five, pentagonal. Basals very large, all hexagonal except the posterior one, on which the small inter-radial plate rests. Radials very large. Arms five, with a single row of plates; dichotomous, the branches uniting so as to form lamellar expansions or networks, which are inrolled. Ventral surface covered by small plates; in the centre five large oral plates. Anal process marginal. Stem thick, circular; canal pentagonal; roots thick. Wenlock Limestone. Ex. *C. rugosus*.

Platycrinus. Calyx monocyclic. Basals three. Radials five, large, tall. One inter-brachial in each area—more in the posterior (anal) area. Arms repeatedly bifurcating; pinnules long. Ventral surface with small plates; anus central or sub-central, usually at the end of a large process. Stem long, round or elliptical. Devonian, but mainly Carboniferous. Ex. *P. lævis*, Carboniferous Limestone.

Encrinus. Calyx basin-shaped, dicyclic. Infra-basals five, very small, generally concealed by the stem. Basals five, pentagonal. Radials five, large, pentagonal; above the radials are the brachials, the first two rows of which are united. Arms bifurcating, with pinnules. Stem long. Trias. Ex. *E. liliiformis*, Muschelkalk.

Apiocrinus (fig. 40). Calyx large. Basals five, thick. Radials low, excavated on their upper surfaces. Arms ten, bifurcating once or twice, formed of a single row of plates. Stem long, cylindrical, base expanded; the articular surfaces of the plates radiately striated. The plates of the upper part of the stem are in contact at the periphery only. The upper part of the stem expands and passes gradually into the calyx; the upper surface of the last plate is provided with five radiating ridges between which the basals lie. Lias to Lower Cretaceous. Ex. *A. parkinsoni*, Bradford Clay.

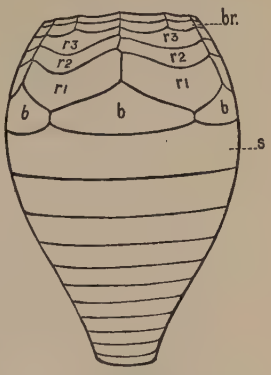


Fig. 40. *Apiocrinus parkinsoni*, from the Bradford Clay. *s*, topmost plate of the stem; *b*, basal plates; *r* 1, radial plates; *r* 2, *r* 3, and *br*, brachial plates. Three-quarters natural size.

Marsupites. Calyx large, globular, plates large and thin; dicyclic. Stem absent. Base formed of a large central pentagonal plate[1]. Infra-basals five, pentagonal. Basals five, hexagonal. Radials five, pentagonal. Arms bifurcating, formed of a single row of plates. Ventral surface of calyx covered with small plates. Anus subcentral. Upper Chalk. Ex. *M. ornatus*.

[1] This plate is regarded by some writers as a dorso-central, representing the dorso-central of *Salenia*, etc.; others consider that it is a centro-dorsal—that is a plate of the stem which has become incorporated into the calyx.

Distribution of the Crinoidea.

In comparison with its abundance in former times the class Crinoidea is but poorly represented at the present day. The most important family is the Comatulidæ (*e.g. Antedon, Actinometra*); this has a wide range in space and depth, the genus *Antedon* extending from the shore-line down to 2900 fathoms. The stalked crinoids are much less abundant than the Comatulidæ, and are found mainly at great depths. In most cases the species of crinoids have only a limited distribution in space.

In the Palæozoic formations the crinoids are much more numerous than the other Echinoderms, their remains in some cases forming the main part of some limestone beds (crinoidal limestone), as for instance in the Carboniferous. None of the other classes are ever sufficiently abundant to be of importance as rock-builders.

The crinoids occur first in the Tremadoc Beds; in the Upper Ordovician *Glyptocrinus* and a few others have been found. In the Silurian they become very much more abundant, attaining here their maximum development; the most important genera are *Cyathocrinus, Ichthyocrinus,* and *Crotalocrinus.* In the Devonian, *Cyathocrinus, Actinocrinus* and others are common; in the Carboniferous, *Actinocrinus, Poteriocrinus,* and *Platycrinus.* Crinoids are rare in the Permian. Throughout the Mesozoic formations they are much less abundant than they are in the Palæozoic; in the Trias the characteristic form is *Encrinus.* In the Jurassic *Antedon, Pentacrinus, Extracrinus, Apiocrinus,* and *Millericrinus* are found, the first two living on to the present day. In the Cretaceous the chief forms are *Marsupites* and *Bourgueticrinus.* In the Cainozoic crinoids are very rare.

CLASS VI. CYSTIDEA.

The Cystideans in general appearance resemble the crinoids. The body consists of a calyx and generally a stem, the latter as a rule being very short. The calyx is in most cases more or less spherical or ovate, with a depression at its base for the articulation of the stem. It is formed of plates which vary in number from thirteen to a hundred or more; when the plates are not very numerous we may distinguish infra-basals, basals, and radials—in some cases the base is monocyclic, in others dicyclic. When the plates are numerous (fig. 41) it is difficult to

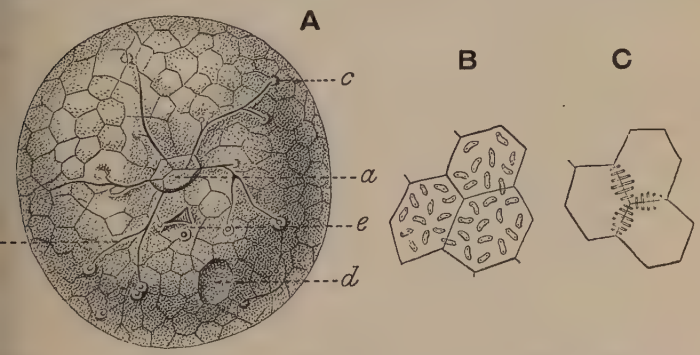


FIG. 41. *A*, *Glyptosphærites leuchtenbergi*, from the Ordovician of Russia. *a*, mouth covered by oral plates; *b*, ambulacral grooves; *c*, socket for the armlet; *d*, anus; *e*, genital aperture (after Volborth). *B*, a few plates of the same enlarged, showing double pores. *C*, Plates of *Echinosphærites*, with pore-rhombs. *B* and *C* enlarged.

recognise any regular arrangement. The radial symmetry in the Cystideans is less perfect than in the crinoids. Arms are present, and vary from three to five in number, but they are very feebly developed or sometimes quite rudimentary; in some forms they are free, but in others fused to the calyx. They may be represented merely by

scattered filaments, articulated to the calyx by sockets on some of the plates. At the summit of the calyx (fig. 41 *A*) there is an aperture (*a*) which is regarded as the mouth and from it radiate food-grooves (*b*). On the upper surface also there is another opening which is probably the anus (*d*); it is covered with plates which form a cone. In some forms there is a smaller aperture near the mouth, which may be a genital pore (*e*). An important feature in the Cystidea is the presence of pores in the plates of the calyx. In a few forms they are absent. They may either be arranged in pairs (fig. 41 *B*) placed in oval depressions or on elevations; or they form what are known as *pore-rhombs* (fig. 41 *C*), consisting of rhombic figures, the outline of which is formed by the pores, half the rhomb being on one plate, and half on an adjoining plate; the pores of the two plates are united by grooves. The number of these pore-rhombs varies considerably in different genera.

The Cystideans resemble the crinoids in the general form of the calyx and stem, in the position of the mouth and anus, and in the possession of food-grooves and arms. But they differ in having the arms feebly developed, in the less perfect radial symmetry and in the presence of numerous pores.

Echinosphærites (fig. 41 *C*). Calyx spherical, without a stem, attached by its base. Plates very numerous, small and polygonal; all the plates with pore-rhombs. Mouth at the summit; anus lateral. Ordovician. Ex. *E. aurantium*.

Lepadocrinus (=*Pseudocrinites*). Calyx ovate, rhombic in outline, with rounded edges; formed of four basal plates followed by three cycles of five plates each. Mouth central. Two to four straight food-grooves, extending to

bout the middle of the calyx, and with projecting edges. Anal aperture near the summit, covered with six triangular plates. Three pore-rhombs, one near the base, wo on the upper surface of the calyx. Stem thick, ircular, rather long, becoming thinner towards the lower xtremity. Silurian. Ex. *L. quadrifasciatus*, Wenlock imestone.

Distribution of the Cystidea.

The Cystideans are comparatively rare fossils, they ange from the Middle Cambrian to the Carboniferous imestone, and attain their maximum development in the Upper Ordovician. In the Menevian we get *Protocystites*; his also occurs in the Tremadoc Beds, and with it *Macrocystella*. In the Upper Ordovician we find amongst others, *Echinosphærites*, *Ateleocystites*, and *Pleurocystites*; in the ilurian *Lepadocrinus* and *Ateleocystites*. In the Devonian here are fewer forms, and in the Carboniferous only one r two genera are known.

CLASS VII. BLASTOIDEA.

In the Blastoids, as in the Cystideans and many of the rinoids, the body consists of a stem and calyx, but the rmer is rarely found attached. The calyx may be pherical, oval, pear-shaped, or bud-like; it is formed most entirely of thirteen plates, arranged in a regular anner. True arms are not present.

In a typical form (*Pentremites*) the calyx (fig. 42) has e following structure. The dorsal part is formed of a cle of three plates—the *basals* (*b*), two of which are ike, and the third smaller. Above the basals is a cycle five *radial plates* (*r*), these are larger than the basals d form the main part of the calyx. At the upper end

of each there is a deep incision, which serves for the reception of the ambulacral area (*a*). Above the radials

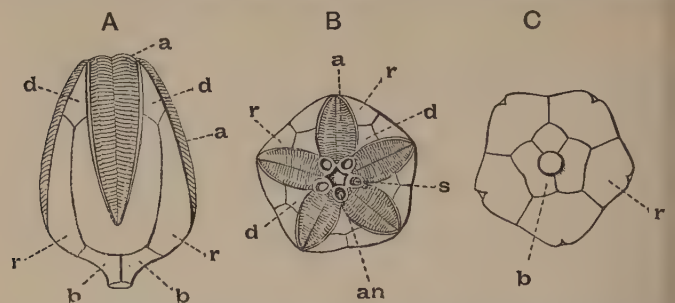


Fig. 42. *Pentremites godoni*, Carboniferous. *A*, lateral; *B*, upper surface; *C*, under surface. *a*, ambulacral areas; *b*, basal plates; *r*, radials; *d*, deltoids; *s*, spiracles around the mouth; *an*, anus. Twice natural size.

and alternating with them occurs a cycle of smaller plates —the *deltoids* (*d*) (or inter-radials). The mouth is placed at the summit of the calyx, in the centre, and around it are five other apertures termed *spiracles* (*s*), one of which is larger than the others and includes the anus (*an*). From the summit the five ambulacral areas (*a*) radiate towards the dorsal surface, they are bordered partly by the deltoids but mainly by the radials. Each ambulacral area (fig. 43) consists of the following plates. Occupying the middle is a long pointed plate (*l*), the *lancet plate*,

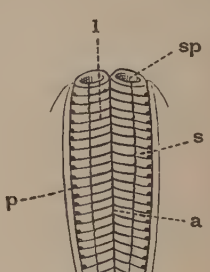


Fig. 43. Ambulacral area of *Pentremites godoni*, Carboniferous. *l*, lancet plate; *s*, side plate; *p*, pore; *a*, ambulacral groove; *sp*, spiracle. Three times natural size.

which is traversed by a longitudinal canal, in which the radial vessel of the water-vascular system was placed. On each side of the lancet plate is a row of small plates, the *side plates* (*s*). Extending down the middle of each ambulacral area is a groove, the *ambulacral groove* (*a*); this in some specimens is covered over by small calcareous plates. At right angles to the ambulacral groove, on each side of it, are numerous transverse grooves. Along the outer margin of the side plates there is a row of pores, the *marginal pores* (*p*), formed by spaces between adjoining plates. When the lancet plate and the side plates are removed from an ambulacral area, we find underneath, in the middle line, an elongated trough-like plate, known as the *under lancet plate*. At the sides of this may be seen the edges of the *hydrospire* (fig. 44 *h*), which consists of a flattened and folded calcareous tube, communicating with the exterior by means of the marginal pores, and ventrally also by the spiracles. A current of water probably passed in through the former openings and out by the latter. In well preserved specimens, the mouth, as in many crinoids, is not visible externally, but is covered over by a roof of small plates. From the margins of the ambulacral areas appendages known as pinnules are given off.

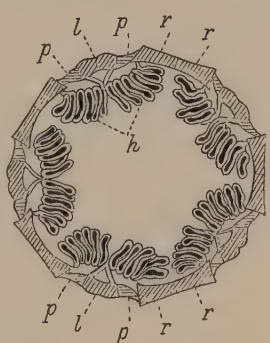


Fig. 44. *Pentremites sulcatus*, Carboniferous. Horizontal section of the calyx. *l*, lancet plate; *p*, side plates; *r*, radial plates; *h*, hydrospires. (After Zittel.) Enlarged.

The other blastoids differ from the one described

mainly in the relative sizes of the plates, in the distance which the ambulacra extend towards the base, and in the amount of folding of the hydrospires.

The most important characters of the Blastoidea as a class are the absence of arms, the monocyclic base consisting of three basals only, the five incised radials, and the structure of the ambulacra and hydrospires.

Granatocrinus. Calyx elliptical, oval, or more or less spherical, in section pentagonal or round. Basals small, not seen in a side view. Radials of variable size. Deltoids generally rhombic, large in some species, small in others. Ambulacra narrow, straight. Lancet plate narrow. Hydrospires simple, often not folded, dilated at the end. Spiracles round or oval, piercing the apices of the deltoids, the posterior one including the anus. Carboniferous Limestone. Ex. *G. derbiensis.*

Distribution of the Blastoidea.

In England the Blastoids range from the Devonian to the Carboniferous, being most abundant in the latter. But in North America they are also found in the Silurian. The English Devonian forms are rare and but little known. In the Carboniferous Limestone the blastoids attain their maximum; ten genera are represented, the most important being *Granatocrinus* and *Codaster*. *Pentremites* occurs in the Carboniferous of America but is not found in Britain.

CLASS. CHÆTOPODA.

The Chætopoda include various forms of 'worms.' The body is segmented and generally the segments are similar. There is a ventral nerve cord and a ring round the œsophagus. A vascular system is present The Chætopoda move either by means of cilia or by bristle-like processes termed setæ. There are three orders, (1) the Archiannelida, *e.g. Polygordius*, (2) the Oligochæta, *e.g.* the common earthworm *Lumbricus*, and (3) the Polychæta. The Archiannelida and the Oligochæta are unknown in the fossil state.

ORDER III. POLYCHÆTA.

The members of this Order are nearly all marine; they are characterised by the possession of numerous setæ which are placed on special processes termed *parapodia*. Tentacles are usually present on the head. Many forms live in tubes, which may consist of carbonate of lime, of chitinous material, or of grains of sand cemented together by a secretion. On account of the possession of this tube the polychætous worms are often found fossil. Other forms, which do not live in tubes, are provided with minute chitinous jaws, and in some formations, especially

the Ordovician and Silurian, these are abundantly preserved.

Serpula. Tube calcareous, long, round, angular or flattened; straight, curved irregularly or sometimes spirally; closed at one end; generally attached to some foreign object by a portion of its surface. Carboniferous to present day. Ex. *S. gordialis*, Chalk.

Spirorbis. Tube calcareous, small, spiral, attached by one side. The spiral either left-handed or right-handed, the last whorl often produced into a free tube. Ordovician to present day. Ex. *S. pusillus* (= *carbonarius*), Carboniferous.

Distribution of the Chætopoda.

Practically all the worms found fossil belong to the Polychæta; the earliest examples occur in the Cambrian beds. In addition to worm-tubes and jaws, we find in the rocks numerous trails and burrows which are considered by some authors to have been formed by worms, but in many cases it is probable that these have been made by other animals such as crustaceans and gasteropods.

CLASS. BRACHIOPODA.

Sub-classes.		*Orders.*
1. Inarticulata.	1.	Atremata.
	2.	Neotremata.
2. Articulata.	1.	Protremata.
	2.	Telotremata.

In the Brachiopods the soft parts of the animal are nclosed in a shell which is formed of two pieces termed *alves*, one placed on the dorsal surface, the other on ne ventral. Generally the body occupies only the pos- erior part of the shell. The interior of the shell is lined y a membrane, the *mantle*, which is a prolongation of ne body-wall and is divided into two lobes, one oc- urring in each valve; the space between the two is nown as the *mantle-cavity*. In most genera the margin the mantle is thickened and carries numerous chitinous tæ. The mouth (fig. 45, *v*) opens into the mantle-cavity, nd leads into an œsophagus which is followed by a omach partly surrounded by the liver, and an intestine; the articulate brachiopods this is short and ends indly, in the inarticulate it is long and ends in an anus hich opens into the mantle-cavity. The nervous system nsists of a ring round the œsophagus, with ganglionic largements from which nerves are given off to the arms, antle, etc. The part of the body-cavity which surrounds

the alimentary canal communicates with the mantle cavity by means of two, or rarely four, funnel-shaped canals, which serve as excretory organs. The body-cavity extends into the mantle as a series of spaces or sinuses; these produce slight depressions on the interior of the valves, and can often be traced as ridges on the internal casts of fossil specimens (fig. 60). The body-cavity is filled with a fluid which is kept in motion by means of cilia. A vesicle found on the dorsal surface of the stomach is probably the heart.

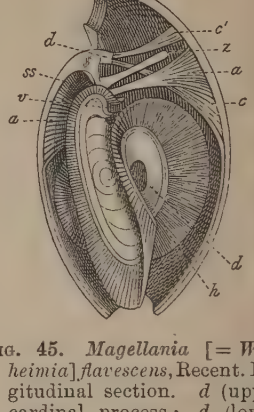


Fig. 45. *Magellania* [= *Waldheimia*] *flavescens*, Recent. Longitudinal section. *d* (upper) cardinal process; *d* (lower) arms; *h*, cirri; *a*, adductor muscle; *c*, *c'*, divaricator muscles; *ss*, septum; *v*, mouth; terminal part of alimentary canal. (After Davidson.) ×1

The brachiopods are never colonial animals. Reproduction takes place sexually, never by budding or fissio The genital organs are placed in the body-cavity, and the sinuses of the mantle. Nearly all forms are dicecious

Generally the greater part of the mantle-cavity occupied by two long processes, given off from the sid of the mouth; these are known as the "*arms*" (fig. 45 since they were at first supposed to serve in locomotion hence the name *Brachiopoda*. The arms are covered wi cirri (*h*), which produce a current of water conveying fo to the mouth. Respiration is carried on mainly by t mantle, but possibly also to some extent by the arms.

Of the two valves of the brachiopod, the ventral nearly always larger than the dorsal; each is produc

into a beak or *umbo* (fig. 46). The ventral umbo is more prominent than the dorsal, and it has generally, either at its apex or just beneath it, an opening. With a very few exceptions the shell of the brachiopod is equilateral, that is to say, a line drawn from the umbo to the opposite margin divides it into two equal and similar parts. This character, combined with the inequality in the size of the valves, renders it easy to distinguish the shell of a brachiopod from that of a lamellibranch. In many forms the two valves are joined together by means of a hinge, these constitute the group *Articulata*; in others they are held together by muscles only, these form the *Inarticulata*. The hinge consists of two short curved processes or teeth given off from the ventral valve near the umbo, which fit into corresponding sockets in the dorsal valve. In some genera (*e. g. Orthis*) the teeth are supported by plates (the *dental plates*) which are fixed to the inside of the ventral valve. The line on which the two valves move in the opening and closing of the shell, is termed the *hinge-line* (fig. 46, *g—h*). In some genera (*Terebratula*) this is short and curved, in others (*Spirifer*, fig. 57) it is long and straight. The posterior part of the shell is that near the hinge (fig. 46, *a*), the anterior is the opposite

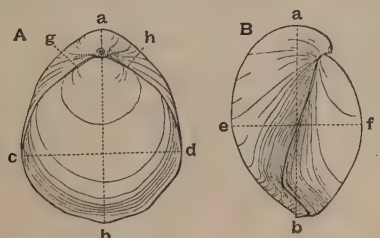


FIG. 46. *Terebratula obesa*, Upper Chalk. *A*, dorsal view. *B*, lateral view. *a*, posterior; *b*, anterior; *a—b*, length; *c—d*, breadth; *e—f*, thickness; *g—h*, hinge-line. Two-thirds natural size.

margin (*b*). The length of the shell is measured from the anterior to the posterior border (*b*—*a*). The breadth is at right angles to this, from one side of the shell to the other (*c*—*d*). The thickness is measured from one valve to the other, perpendicular to the length and breadth (*e*—*f*). In some genera (*e. g. Terebratula*) the length is greater than the breadth, in others (*e.g. Strophomena*) the breadth is greater. Between the hinge-line and the umbo there is in some brachiopods (*e.g. Cyrtia*, fig. 47) a flat or slightly concave portion of the shell, usually triangular, on which the ornamentation of the rest of the shell is absent, the surface being either smooth or striated; this is known as the *area*. It may occur on both valves (*e.g. Orthis*), but is often found on the ventral valve only.

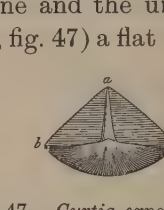


Fig. 47. *Cyrtia exporrecta*, Wenlock Limestone. *abc*, area; *b*—*c* hinge-line. Natural size.

Nearly all living brachiopods are fixed to a rock or other object; but a fair number of fossil forms were free especially in old age (*e.g. Productus*). Some, like *Crania* are attached by one valve being soldered to the rock, others (*e.g. Strophalosia*) by spines given off from the surface of the shell. More commonly however the attachment takes place by means of a stalk or peduncle; this is a cylindrical process, in some genera long, in others short, connected with the mantle, and passing out either through an opening in the ventral valve (fig. 48 *A*, *f*) or between the umbones (*e.g. Lingula*, fig. 52). It is composed mainly of horny material; but in some forms there are muscular layers also.

The opening for the passage of the peduncle varies considerably in different genera, and is a feature of great

importance in classification. The simplest case is that found in *Lingula* and some others, in which the opening is shared by both valves. In other types we find that the peduncle-opening is confined to the ventral valve; sometimes it is in the form of a triangular fissure just under the umbo as in *Orthis* (fig. 56). In *Rhynchonella* the triangular fissure is closed by two plates, forming what is known as the *deltidium*, near the centre of which is a small circular opening or *foramen* for the peduncle. In *Magellania* (fig. 48 *A*) the foramen is quite at the apex of the umbo, its lower boundary being formed by the deltidium (*d*). In *Discina* the opening is completely enclosed by the shell and is often near the centre of the valve; consequently the peduncle comes out at right angles to the plane of the valves. In some genera the triangular fissure found under the umbo is more or less completely filled up by a shelly growth known as the *pseudo-deltidium*; this at first sight closely resembles the deltidium, but is really of quite a different nature. It is secreted by the dorsal surface of the mantle and the peduncle, although attached to the ventral valve, whereas the deltidium is formed by the edge of the ventral lobe and originally consists of a pair of plates. It is also developed earlier than the deltidium and becomes fused to the ventral valve.

The two valves of the brachiopod can be opened and closed by means of muscles (fig. 45); those which open them are called the *divaricators* (*c*, *c'*), those which close them, the *adductors* (*a*). When the soft parts of the animal have been removed the places where the muscles were attached to the interior of the shell are indicated by a difference in the surface such as striation, or by slight depressions or elevations; these markings are termed the *muscular im-*

pressions. In the articulate brachiopods there are generally five or six pairs of muscles. In the genus *Magellania* there are two pairs of divaricators (fig. 45 *A*, *c*, *c'*) and one of adductors (*a*). Both pairs of the former are attached to a process (the *cardinal process*, fig. 48 *B*, *c*, *c'*) on the dorsal valve between the teeth sockets, and one pair join the ventral valve near its centre (fig. 48 *A*, *c*), and the other pair, which are smaller, are attached nearer the posterior border (*c'*). Hence the dorsal valve forms with these two pairs of muscles a lever of the first order. The adductor muscles are united to the ventral valve near the centre (fig. 48 *A*, *a*) and form a single impression divided by a median line; these muscles bifurcate before reaching the dorsal valve and there form four impressions (fig. 48 *B*, *a*, *a'*). There are also muscles attached to the peduncle which serve to move the shell

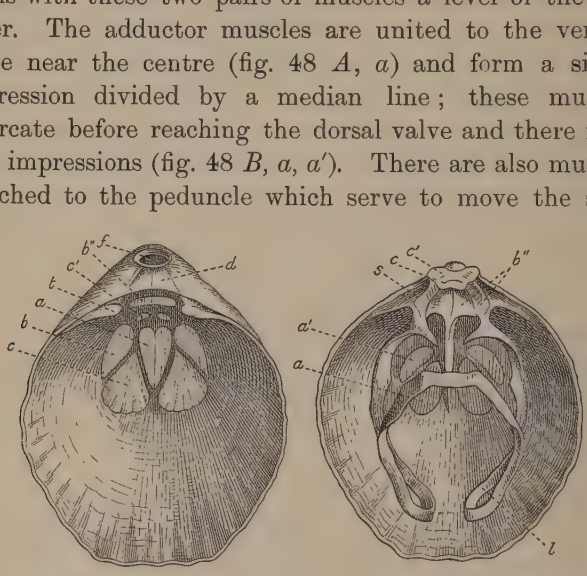


FIG. 48. *Magellania* [= *Waldheimia*] *flavescens*, Recent. *A*, Interior of ventral valve. *f*, foramen; *d*, deltidium; *t*, teeth; *a*, impressions of adductor muscles; *c*, *c'*, impressions of divaricator muscles; *b*, *b''*, muscles of the peduncle. *B*, Interior of dorsal valve. *c*, *c'*, cardinal process; *b''*, hinge-plate; *s*, dental sockets; *l*, loop; *a*, *a'*, adductor impressions; *c*, point of attachment of the smaller divaricator. (After Davidson.) $\times 1\frac{1}{2}$.

bodily, one pair of these being united to the dorsal valve (fig. 48 *B*, *b''*), the others to the ventral (*A*, *b*, *b''*). In the Inarticulata the muscles are much more complicated; thus, in *Lingula* (fig. 52) we find, in addition to the adductors and divaricators, muscles for moving one valve backward or forward in relation to the other; and others for giving a slight rotary motion.

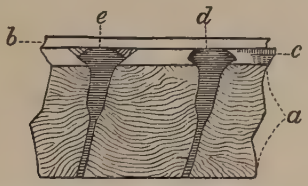
The arms, already mentioned as occupying in most genera the main part of the mantle-cavity, are generally coiled up. In some forms they can be protruded a greater or shorter distance. Sometimes they are supported on a calcareous framework—the *brachial skeleton*—which is attached to the posterior part of the dorsal valve. In *Rhynchonella* (fig. 59 *B*, *c*) the brachial skeleton consists of two short curved processes. In *Terebratula* (fig. 62) there is a ribbon-like band forming a short loop. In *Stringocephalus* (fig. 64) the loop is more extensive and runs parallel to and near the margin of the valves. In *Magellania* (fig. 48 *B*) the loop extends nearly to the anterior margin of the shell and is then bent back upon itself. In other genera, the brachial skeleton is in the form of two spiral ribbons; in *Spirifer* (fig. 57 *A*) the apices of the spirals are directed towards the lateral margins of the shell, in *Glassia* they point inwards, in *Atrypa* (fig. 58 *A*) upwards to the centre of the dorsal surface. The brachial skeleton is absent in all the inarticulate genera, as well as in some of the articulate forms such as *Productus* and *Chonetes*.

The development of the brachial skeleton has been studied in some modern species of *Terebratulina*, *Magellania*, and *Terebratella*. In *Terebratulina* the adult form is reached almost directly; but in *Magellania* the brachial skeleton passes through various stages before the adult

condition is attained; and it is noteworthy that thes stages are similar to the adult forms of certain othe genera. Thus in the earliest stage of *Magellania venos* the brachial skeleton is like that found in the genu *Magasella*; then it passes into one similar to *Terebratella* and last the adult form of *Magellania* is attained. An other striking fact is that some species of *Magellani* have a development differing from this; thus *M. septiger* passes through stages distinctive of the genera *Centronell* *Ismenia*, and *Terebratella*. If the stages through whic an individual passes in its development be taken t indicate its ancestry, then it follows that in *Magellani* there are two groups of species having different ancestor and these two groups must therefore be regarded a constituting two distinct genera.

The largest brachiopod known, is *Productus gigante* from the Carboniferous Limestone, which has a breadt of twelve inches; the size of the shell varies from thi down to about a quarter of an inch. Generally the she is very thin, but in some forms (*e.g. Productus* (*Daviesiell* *llangollensis*) it is thick and massive. The external for varies considerably: it may be globular, ovoid, hem spherical, quadrilateral, or triangular. Usually bot valves are convex, but in some genera, one is plane th other convex, or one may be concave and the othe convex; in the last case the space in the interior small. Sometimes there is a depression or sulcus on or valve (generally the ventral) and a corresponding ridg on the other valve. The surface of the shell is som times quite smooth, but is often punctate, or ornamente with striæ or ribs, which generally radiate from th umbones, but are occasionally concentric. A few form possess spines which are fused on to the shell.

In the Articulata the shell is mainly calcareous. In he genus *Magellania* it is formed of three layers (fig. 49); he inner (*a*), next the mantle, is the thickest and most



IG. 49. Vertical section of shell of *Magellania* [= *Waldheimia*] *flavescens*, Recent. *a*, prismatic layer; *b*, epidermal layer; *c*, outer calcareous layer; *e*, *d*, canals traversing the calcareous layers. (After King.) Magnified.

mportant, and consists of flattened prisms of calcite, rranged obliquely to the surface of the shell, each prism eing encased in a membrane, which of course has dis-ppeared in the fossil examples. The middle layer (*c*) is amellated and also calcareous. The outer (*b*) is the pidermal layer and consists of chitinous material. The nner and middle layers are raversed by canals (figs. 49, , *d*, 50) running at right ngles to the surface of the hell, and contain prolongations f the mantle. The shell is ecreted by the mantle, its utermost border producing he epidermal layer, a zone ust within this forming the amellated layer, and the emainder giving rise to the prismatic layer which radually encroaches on the preceding; hence the last ayer is the only one which can subsequently increase

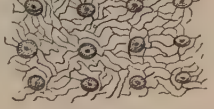


FIG. 50. Horizontal section through the prismatic layer of *Terebratula maxillata*, from the Great Oolite, showing prisms and canals. Magnified.

in thickness. In many forms the lamellated layer is absent; and some (*e.g. Rhynchonella*) possess no canals traversing the calcareous layers.

The shell of the Inarticulata has a different structure. In *Lingula* it consists of alternating calcareous and chitinous layers, the calcareous material being mainly phosphate of lime. The canals which traverse these layers are more numerous and much smaller than those found in the articulate forms.

The different stages in the growth and decline of the brachiopod shell, from the embryo up to old age, have been carefully studied by Beecher. He finds that the shell in the earliest or embryonic stage is similar in character in all the genera which he has examined; he calls this embryonic shell the *protegulum*. Sometimes the protegulum may be found at the umbones of adult shells, generally however, owing to its delicate nature it has been worn off; it is semicircular or semi-elliptical in form, and is marked with concentric lines of growth; its size varies from ·05 to ·60 millimetre. From the

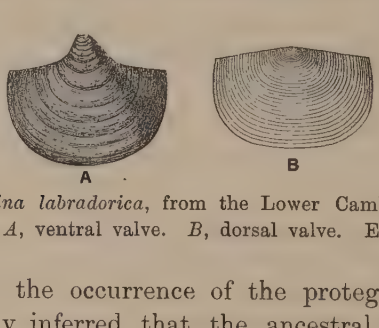


FIG. 51. *Paterina labradorica*, from the Lower Cambrian (Olenellus Beds). *A*, ventral valve. *B*, dorsal valve. Enlarged.

constancy of the occurrence of the protegulum it may be reasonably inferred that the ancestral form of the Brachiopoda possessed throughout life a shell similar to the protegulum. This is borne out by the fact that in the Lower Cambrian (*Olenellus* Beds) of North America

there occurs a brachiopod of this nature, to which Beecher has given the appropriate name of *Paterina* (fig. 51). The probability is therefore that all brachiopods have descended from a pre-Cambrian genus either identical with or closely allied to *Paterina*.

The Brachiopoda are divided by nearly all authors into two groups—the *Inarticulata* and the *Articulata*[1]—the characters of which have already been described. Recently Beecher has proposed to divide the Class into four Orders, based to a large extent on the character of the peduncle-opening (p. 119). Two of these Orders (the *Atremata* and the *Neotremata*) include the inarticulate genera; the other two (the *Protremata* and the *Telotremata*) comprise the articulate forms.

SUB-CLASS I. INARTICULATA.

The valves are not provided with teeth but are held together by muscles only. The intestine is long and ends in an anus. There is no brachial skeleton.

ORDER I. ATREMATA.

The peduncle passes out between the umbones; the opening being shared by both valves. *E.g. Lingula.*

[1] These have also received other names; the Inarticulata being known by some authors as the Lyopomata, the Ecardines, the Pleuropygia, or the Tretenterata; and the Articulata as the Arthropomata, the Testicardines, the Apygia, or the Clistenterata.

Lingula (fig. 52). Shell thin, nearly equivalve, compressed, elongate-ovate or quadrilateral, tapering towards the umbones, slightly gaping at the extremities. Dorsal valve a little shorter than the ventral. Hinge-line slightly thickened. Twelve muscular impressions in each valve, but only feebly marked. Surface of shell smooth, or concentrically or radiately striated. Peduncle long, passing between the umbones. Shell composed mainly of alternating layers of phosphate of lime and chitinous material. Cambrian[1] to present day. Ex. *L. anatina* Recent; *L. ovalis*, Kimeridge Clay.

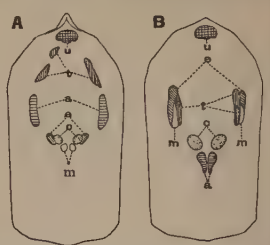


Fig. 52. *Lingula anatina*, Recent. Interior of valves showing muscular impressions. *A*, ventral valve. *B*, dorsal valve. *u*, umbonal muscle; *t*, transmedians; *c*, centrals; *a*, anterior laterals; *m*, middle laterals; *e*, external laterals. $\times \frac{1}{2}$.

Lingulella. Distinguished from *Lingula* by the presence, in the ventral valve, of a distinct slit and of a high hinge-area. Cambrian to Ordovician. Ex. *L. davisi* Lingula Flags.

ORDER II. NEOTREMATA.

The peduncle passes out at right angles to the plane of junction of the two valves, and the opening is confined to the ventral valve. In the lower types the opening is in the form of a slit at the margin of the valve; but in

[1] The internal characters of many of the species found in the Lower Palæozoic formations are only imperfectly known; it is therefore possible that these early forms may not belong to this genus.

the higher forms it is completely surrounded by shell, and is often near the centre of the valve. *E.g. Discina.*

Discina (group). Shell sub-orbicular, or sub-elliptical, surface smooth or covered with striæ of growth. Valves more or less conical, the summits of both sub-central or sub-posterior. Animal attached by a peduncle passing through an opening in the ventral valve, which is placed either near the summit or a little behind it. Four adductor impressions. Cambrian to present day.

The definition of *Discina* given above includes the three genera *Discina* (restricted), *Discinisca*, and *Orbiculoidea*; in the Palæozoic specimens it is generally difficult, owing to imperfect preservation, to make out their distinguishing features; consequently it will often be convenient to use the term *Discina* in a wide sense. The characters of the three forms are:—

Discina (restricted). Both valves convex. Peduncle-opening small, externally near the middle of the valve, passing through the shell obliquely forwards. The only species definitely known is *D. striata*, Recent.

Discinisca. Ventral valve flattened; behind the apex is a disc, which is depressed externally and interrupts the continuity of the lines of growth. The disc is perforated for the peduncle by a fissure which passes directly, not obliquely, through it. Perhaps Tertiary or earlier. Ex. *D. lamellosa*, Recent.

Orbiculoidea. Ventral valve flattened; on the surface just behind the apex is a narrow furrow, which is perforated at the point farthest from the apex, the perforation passing through the shell obliquely backwards. Silurian to Carboniferous, perhaps also Mesozoic. Ex. *O. morrisi*, Wenlock Limestone.

Crania (fig. 53). Shell calcareous, quadrangular or sub-circular, smooth or furnished with radiating ribs, fixed by the ventral valve; without peduncle-opening. Ventral valve depressed-conical; dorsal larger than the ventral,

conical with a sub-central apex. Internal border of both valves covered with coarse granulations. Two pairs o

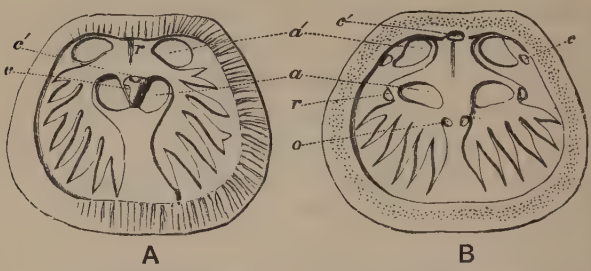


FIG. 53. *Crania anomala*, Recent. A, interior of ventral valve; B, dorsa valve. *a*, anterior adductors; *a'*, posterior adductors; *c*, posterio adjustors; *c'*, cardinal muscle; *r*, *o*, central and external adjustors (From Woodward.) Twice natural size.

well-marked adductor impressions in each valve (*aa'*) the posterior pair near the margin, the anterior near the centre of the valves and close together, especially so in the ventral valve. Also other smaller muscular impressions. Ordovician to present day. Ex. *C. ignaber gensis*, Upper Chalk.

SUB-CLASS II. ARTICULATA.

The valves articulate by means of two teeth on the ventral valve which fit into sockets on the dorsal. The intestine is short and ends blindly. A brachial skeleton may or may not be present.

ORDER I. PROTREMATA.

A pseudo-deltidium is developed, but may disappear in the adult. The peduncle-opening is at the margin o

the valve in the form of a fissure either opening at the hinge-line or more or less completely closed by the pseudo-deltidium. *E.g. Orthis.*

Productus (fig. 54). Shell free, generally transverse (*i.e.* broader than long) but sometimes elongated, often produced into ears in the umbonal region. Dorsal valve

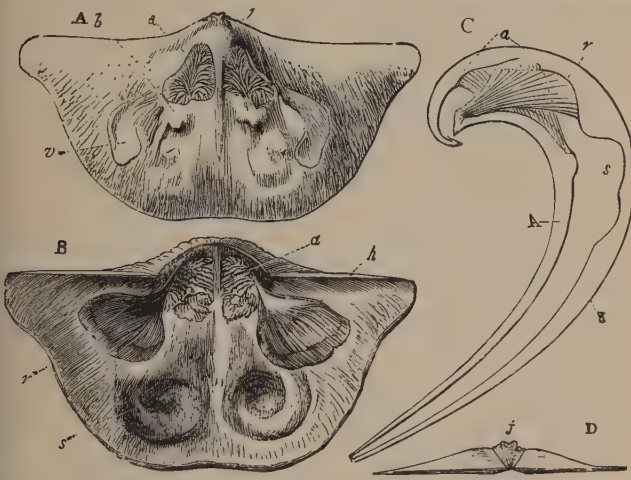


FIG. 54. *Productus giganteus*, Carboniferous Limestone. A, interior of dorsal valve; B, interior of ventral valve; C, ideal section of both valves; D, dorsal hinge-line. *j*, cardinal process; *a*, adductor; *r*, divaricator; *h*, ventral area; *b*, brachial prominence (?); *s*, hollows occupied by the spiral arms; *v*, reniform impressions. (From Woodward.) One-third natural size.

concave. Ventral valve very convex, often sharply bent, sometimes with a median sinus; umbo large, recurved, imperforate. Hinge-line straight, teeth absent or rudimentary. Area linear or absent. Surface ornamented with radiating ribs, crossed by concentric folds, especially in the umbonal region. Tubular spines, especially in the region of the umbo and ears. Muscular impressions

strongly marked; in the ventral valve the adductors (*a*) are near the umbo, and in front of them the divaricators (*r*) are inserted. A prominent cardinal process (*j*) on the dorsal valve which is continued as a median ridge in the interior. No brachial skeleton. Devonian to Permian. Ex. *P. semireticulatus*, Carboniferous Limestone.

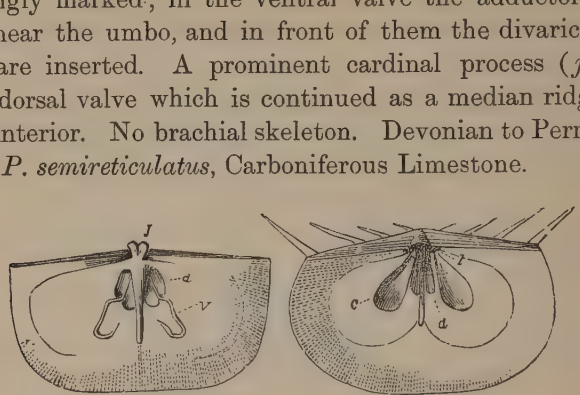


Fig. 55. *Chonetes* from the Devonian. A, dorsal; B, ventral valve. *a*, adductor impressions; *c*, divaricators; *t*, teeth; *v*, vascular impressions; *j*, cardinal process. (From Woodward.) Enlarged.

Chonetes (fig. 55). Shell transverse, semicircular, concavo-convex, or sometimes plano-convex. Hinge-line straight, forming the greatest width of the shell. Teeth strong. An area on each valve. Upper margin of area of ventral valve furnished with a row of hollow, diverging spines, which increase in length towards the terminations of the hinge-line. Peduncle-opening more or less completely closed by a pseudo-deltidium. Muscular impressions faintly marked. Surface ornamented with radial striæ. Silurian to Permian. Ex. *C. striatella*, Upper Ludlow.

Leptæna. Shell concavo-convex, semicircular or nearly quadrangular, ornamented with small radiating ribs, crossed by concentric folds on the flatter parts, anterior part bent sharply, often at a right angle. Space between the two valves very small. Hinge-line straight, forming the greatest width of the shell. An area on each

valve, that of the dorsal valve linear, that of the ventral valve larger with a median notch covered by a pseudo-deltidium. Umbo of ventral valve perforated by a small circular foramen except in old age. Two strong diverging teeth in the ventral valve. Muscular impressions—in the ventral valve, two narrow adductors surrounded by two large divaricators; in the dorsal two small adductors near the centre of the valve, behind which are two larger adductors. Ordovician to Carboniferous. Ex. *L. rhomboidalis*[1], Bala Beds, etc.

Strophomena. Shell concavo-convex, semicircular or semi-elliptical, ornamented with radiating ribs. Hinge-line straight, forming the greatest width; a pseudo-deltidium is present. Ventral area conspicuous, the dorsal narrow. Teeth diverging widely, supported by plates, which are produced into ridges nearly surrounding the muscular area; the latter is divided by a median ridge. Dorsal valve with a ridge separating two large adductor impressions, in front of which are two narrow impressions. Ordovician and Silurian. Ex. *S. antiquata*, Wenlock limestone.

Orthis (fig. 56).[2] Outline sub-circular or quadrate. Both valves convex. Surface radiately ribbed or striated. Hinge-line straight, sometimes equal to the width of the shell, but generally shorter. An area on either valve, each divided by a median triangular fissure. In the ventral valve two large teeth, supported by dental plates. Four muscular impressions in the dorsal valve. Two long narrow

[1] This species is usually placed in the genus *Strophomena*, but recent work has shown that it is really the type species of *Leptæna*.

[2] A large number of species showing a great deal of variation have been placed in this genus, and according to the work of recent authors it must be regarded as a group including several different genera.

impressions (*d*) with two smaller ones (*a*) between them in the ventral. Cambrian to Carboniferous. Ex. *O. calli*

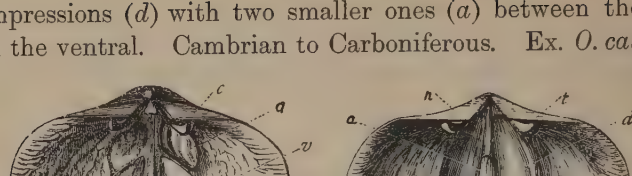


Fig. 56. *Orthis striatula*, Devonian. A, interior of dorsal valve B, ventral valve. *c*, curved brachial processes (cruras); *v*, genita impressions; *h*, area; *t*, teeth; *a*, adductors; *d*, divaricators (From Woodward.) Natural size.

gramma, Ordovician and lower part of Silurian; *O. flabel lulum*, Bala Beds; *O. resupinata*, Carboniferous Limestone

ORDER II. TELOTREMATA.

The peduncle-opening is confined to the ventral valve and is placed either at the umbo or beneath it. A delti dium is developed. *E.g. Magellania.*

Spirifer (fig. 57). Shell transverse, more or les

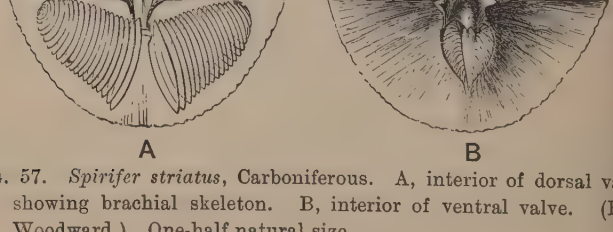


Fig. 57. *Spirifer striatus*, Carboniferous. A, interior of dorsal valve showing brachial skeleton. B, interior of ventral valve. (Fro Woodward.) One-half natural size.

triangular, biconvex, smooth or ornamented with ribs or striæ. Often with a sinus on the ventral valve and a ridge on the dorsal. Hinge-line long and straight. An area on each valve, the ventral one triangular, often transversely striated, divided by a median triangular slit, which is partly closed by a deltidium; dorsal area small, also with a median slit. Teeth supported by dental plates. Brachial skeleton often filling a great part of the interior of the shell, in the form of two spiral ribbons, with their apices directed laterally. Silurian to Permian. Ex. *S. striatus*, Carboniferous Limestone. The sub-genus *Spiriferina* possesses a high median septum in the ventral valve. Devonian to Lias. Ex. *S. walcotti*, Lias.

Cyrtia (fig. 47). Area on the ventral valve very large, with a convex deltidium. Dental plates well developed but not joining. Brachial skeleton as in *Spirifer*, but the apices of the spires are nearer the hinge-line. Silurian (? Devonian). Ex. *C. exporrecta*, Wenlock Limestone.

Uncites. Shell elongate-oval, biconvex, striated. Hinge-line curved, no area. Umbo of the ventral valve prominent and incurved, foramen closed in the adult; deltidium concave. Dental plates strong. Apex of dorsal valve recurved and partly hidden in the ventral valve; cardinal process prominent. Brachial skeleton spiral, the apices of the spires directed laterally. Devonian. Ex. *U. gryphus*.

Atrypa (fig. 58). Shell sub-circular, biconvex, ornamented with radiating ribs, often crossed by lines of growth. Ventral valve depressed in front; dorsal valve often much inflated. Hinge-line curved, no area. A small circular foramen, and a small deltidium. Ventral

valve with two strong crenulate teeth; muscular impressions grouped in the centre of the valve. Brachial skeleton in the form of two spirals with their apices

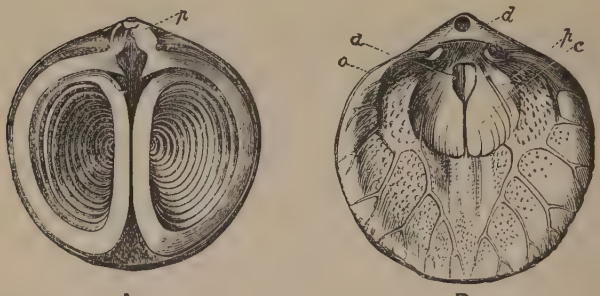


Fig. 58. *Atrypa reticularis*, Wenlock Limestone. A, dorsal valve showing brachial skeleton. B, interior of ventral valve. *a*, impressions of adductor muscles; *c*, divaricator muscles; *p*, muscles of peduncle; *o*, genital impression; *d*, deltidium. (From Woodward.) Natural size.

directed toward the centre of the dorsal valve; the two spires joined by a band near the umbo. Ordovician to Trias. Ex. *A. reticularis*, Wenlock Limestone.

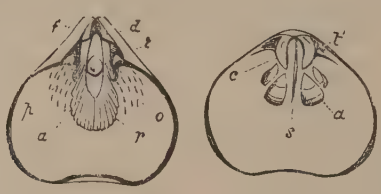


Fig. 59. *Rhynchonella* (*Hemithyris*) *psittacea*, Recent. A, ventral; B, dorsal valve. *f*, foramen; *t*, teeth; *a*, adductor impressions; *r*, divaricator impressions; *p*, peduncular impressions; *o*, genital impressions; *t'*, dental sockets; *c*, brachial skeleton; *s*, septum. (From Woodward.) Natural size.

Rhynchonella (figs. 59, 60). Shell triangular, elon-

gated, or rounded, very convex, not perforated by canals, usually ornamented with radiating ribs. A sinus on the ventral valve and a corresponding ridge on the dorsal.

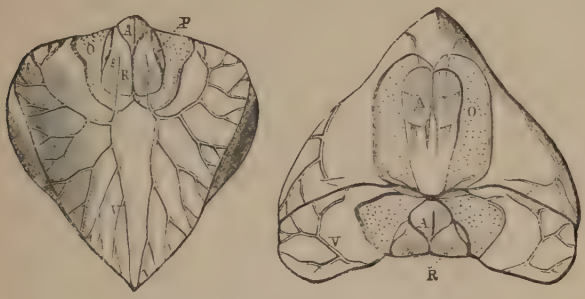


Fig. 60. *Rhynchonella acuminata*, Carboniferous Limestone. Internal casts. V, 'vascular' impressions; O, genital impressions; A, adductors; R, divaricators; P, muscles of the peduncle. (From Woodward.) Natural size.

Umbo small, acute, recurved; foramen enclosed by the deltidium. Ventral valve with two strong teeth, muscular impression in middle of valve. Brachial skeleton reduced to two short, free, curved lamellæ. Ordovician[1] to present day. Ex. *R. cynocephala* and *R. spinosa*, Inferior Oolite; *R. plicatilis*, Upper Chalk; *R. psittacea*, Pliocene and Recent.

Stricklandia. Shell large, oval, ornamented with ribs; valves nearly equal, sometimes with a fold and a sinus. An area on the ventral valve. A short median septum in the ventral valve from which arise two plates forming a small chamber under the umbo. Silurian. Ex. *S. lens*, Llandovery Beds.

[1] The Palæozoic species differ in several respects from the later ones and are regarded by some authors as belonging to other genera.

Pentamerus (fig. 61). Shell oval, ornamented with ribs, rarely smooth. Ventral valve the most convex. Dorsal valve usually with a fold in front, ventral valve with a corresponding depression. Umbo of ventral valve

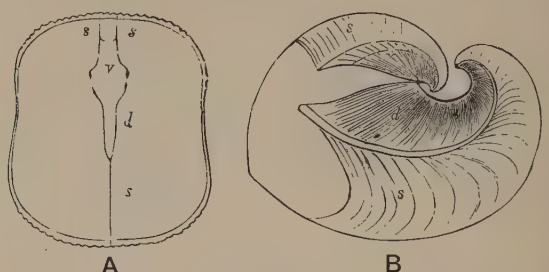


Fig. 61. *Pentamerus* (*Conchidium*) *knighti*, Aymestry Limestone. A, transverse section; B, longitudinal section. *ss*, dorsal septa *s*, ventral septum; *d*, dental plates. (From Woodward.) One-half natural size.

sharp, strongly incurved, usually touching the dorsal valve and concealing the triangular aperture. No area nor deltidium. Dental-plates (*d*) trough-like, converging in the ventral valve to form a median septum (*s*); in the dorsal valve two contiguous septa (*ss*). Silurian to Devonian. Ex. *P. galeatus*, Wenlock Limestone.

Terebratula (figs. 46, 62). Shell biconvex; oval elongate, or rounded; surface smooth; often with two folds on the dorsal valve and two corresponding sinuses on the ventral. Hinge-line curved. Umbo of ventral valve truncated by a circular foramen, having a deltidium at its base. Brachial skeleton in the form of a short loop ex-

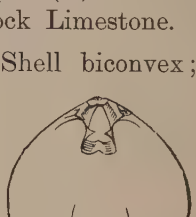


Fig. 62. *Terebratula* (*Liothyris*) *vitrea*, Recent. Interior of dorsal valve, showing the brachial skeleton. (From Woodward.) Reduced.

tending only about a third of the length of the shell. Devonian to present day. Ex. *T. maxillata*, Inferior and Great Oolite.

Magellania (= *Waldheimia*) (fig. 48). Distinguished from *Terebratula* by the longer brachial loop, extending to at least half the length of the shell, and by a median septum in the dorsal valve, which is, however, sometimes rudimentary. Lias to present day. Ex. *M. flavescens*, Recent; *M. cornuta*, Lias; *M. impressa*, Oxford Clay.

Terebratulina (fig. 63). Form similar to *Terebratula*. Ornamented with fine radiating ribs. Umbo short, foramen large, deltidium small. Two ear-like processes at the sides of the dorsal umbo. Brachial loop short, with a ring formed by the junction of the two branches. Jurassic to present day. Ex. *T. striata*, Chalk.

Fig. 63. *Terebratulina caput-serpentis*. Interior of dorsal valve. Recent. (From Woodward.) Enlarged.

Stringocephalus (fig. 64). Shell smooth, nearly circular in outline. Ventral valve with a sharp prominent umbo; area present. Foramen large in young individuals, but smaller and oval in the adult on account of the development of the deltidium. Teeth large. Ventral valve with a median septum (*vs*), which extends from the umbo almost to the front of the valve, and increases in height towards the latter. Dorsal valve less convex, with a small septum (*s*), and a long slightly curved cardinal process (*j*), divided at its extremity to embrace the ventral septum. The brachial skeleton

consists of two branches arising from the hinge-plate (p) which pass to the middle of the shell (c) and are then

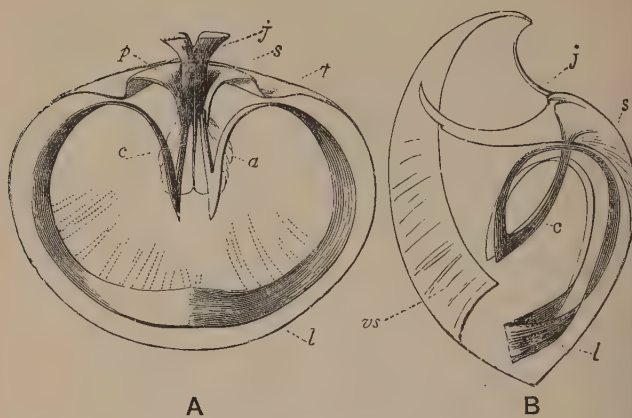


Fig. 64. *Stringocephalus burtini*, Devonian. A, Dorsal valve. B, Profile *a*, adductor; *c*, crura; *l*, loop; *j*, cardinal process; *p*, hinge-plate *s*, dorsal septum; *vs*, ventral septum; *t*, dental sockets. (From Woodward.) One-half natural size.

sharply bent back and form a ribbon (l) parallel to the margin of the valve. Devonian. Ex. *S. burtini.*

Distribution of the Brachiopoda.

The Brachiopods are all marine, and are found in all parts of the world; at the present time they are much less numerous than in former periods of the earth's history there being only about 120 living species. Many forms occur more abundantly where the sea-bottom is rocky, or stony, or formed of corals, than where it is soft or muddy; frequently they are much localised, being found in enormous numbers at one spot, whilst, in the adjoining areas

hey are sparsely distributed. About half of the existing pecies are found at depths of less than 100 fathoms, and everal of these do not extend beyond this limit. Below 50 fathoms they soon become comparatively rare, but a ew species (*e.g. Terebratulina wyvillei*) occur down to 900 fathoms. Some genera, as for instance *Lingula*, do ot occur below a depth of a few fathoms. In the ittoral zone (see p. 198) Brachiopods are less numerous han elsewhere, only 17 species occurring in it. The aminarian zone contains 46 species, of which 15 (in- uding 5 species of *Lingula*) are confined to it. In the one of Nullipores there are rather fewer forms than in he preceding one. The zone of Brachiopods and Corals the richest in Brachiopods, containing no less than 58 pecies or varieties. In the Abyssal zone 30 species have een dredged, but the greater number come from the pper part of the zone ; the Inarticulata are poorly presented here. Geographically, the Brachiopoda, which ve in comparatively shallow water, are distributed in pro- nces, agreeing generally with the Molluscan provinces . 197). These are characterised by the presence abundance of certain species, and are determined ainly by climate. With one or two exceptions all the ecies found in the Northern Hemisphere are distinct m those in the Southern. Amongst the forms limited the cold northern regions may be mentioned *Rhyn- nella psittacea* and *Magellania septigera*, whilst *R. ricans* and *M. venosa* are found only in cold southern gions. A few species, as for example *Terebratulina out-serpentis*, have a very wide geographical distribu- n, extending from polar to tropical regions, and they o have a great range in depth, the form mentioned ng found from the shore-line down to 1180 fathoms.

The species confined to shallow water have generally a much more limited geographical range than those found in deeper water; and the polar or boreal species have a wider range than the tropical, since they can find the same temperature in lower latitudes at greater depths.

The Brachiopods are very abundant as fossils, especially in the Palæozoic formations. The earliest forms occur in the Lower Cambrian (*Olenellus* Beds); it is remarkable that in this division in North America no less than eleven genera are represented, of which *Lingulella*, *Paterina*, *Kutorgina*, *Obolella*, and *Orthis* may be mentioned. In the Ordovician System the Brachiopods are much more numerous than in the Cambrian, and they attain their maximum in the Silurian; their decline begins with the Devonian and becomes especially marked in the Mesozoic period.

The chief genera met with in the different systems are:—

Cambrian. *Lingula*, *Lingulella*, *Kutorgina*, *Obolella*, '*Discina*' and *Orthis* (the last being almost the only representative of the Articulata).

Ordovician. *Lingula*, *Orthis*, *Strophomena*, and *Leptæna*.

Silurian. *Lingula*, *Orbiculoidea*, *Atrypa*, *Orthis*, *Meristella*, *Spirifer*, *Rhynchonella*[1], *Pentamerus*, *Leptæna*, *Strophomena*, and *Chonetes*.

Devonian. *Uncites*, *Stringocephalus*, *Atrypa*, *Orthis*, and *Spirifer*.

Carboniferous. *Lingula*, *Orbiculoidea*, *Chonetes*, *Athyris*, *Orthis*, *Spirifer*, *Productus*, *Terebratula*, and *Rhynchonella*[1]. *Spirifer* and *Productus* are particularly abundant.

[1] See note on p. 135.

Permian. *Productus*, *Strophalosia*, *Spirifer*, and *Rhynchonella*.

Mesozoic. Most of the important Palæozoic genera die out before the commencement of the Mesozoic. This period is remarkable for the extraordinary abundance of *Terebratula*, *Magellania*, and *Rhynchonella*. Other genera which occur are *Lingula*, *Crania*, *Terebratulina*, and *Terebratella*. *Spiriferina* is found in the Lias.

Tertiary. Brachiopods are very poorly represented; the following forms occur, but are not common:—*Lingula*, *Terebratula*, *Terebratulina*, and *Magellania*.

CLASS. POLYZOA[1].

Sub-classes.	*Orders.*	*Sub-orders.*
1. Ectoprocta.	1. Phylactolæma.	
	2. Gymnolæma....	1. Cyclostomata.
		2. Cheilostomata.
		3. Ctenostomata.
2. Entoprocta.		

With the exception of the genus *Loxosoma* all the Polyzoa are colonial animals, numerous individuals living in association. The colony is nearly always fixed, and may be arborescent, laminar, almost massive, or encrusting shells and stones. The entire colony is known as the *zoarium*; each individual (fig. 65 *A*) has a sac-like form; at the upper end there is a platform or disc, the *lophophore*, on which tentacles (*t*) are placed, arranged either in a circle or in the form of a horseshoe. In most forms the tentacles are not contractile, but are provided with cilia, which produce a current of water that conveys food to the mouth (*o*). The anal aperture (*a*) is near the mouth, generally below the lophophore, but in some forms within the circle of tentacles. On account of this approximation of the mouth and anus the alimentary canal is bent into a U-shape; in it may be distinguished œsophagus (*œs*), stomach (*st*) and intestine (*int*). Between the alimentary canal and

[1] The name *Bryozoa* is used for this class by many authors.

he body wall is a spacious body-cavity. The nervous ystem consists of a single ganglion (*g*) placed on the

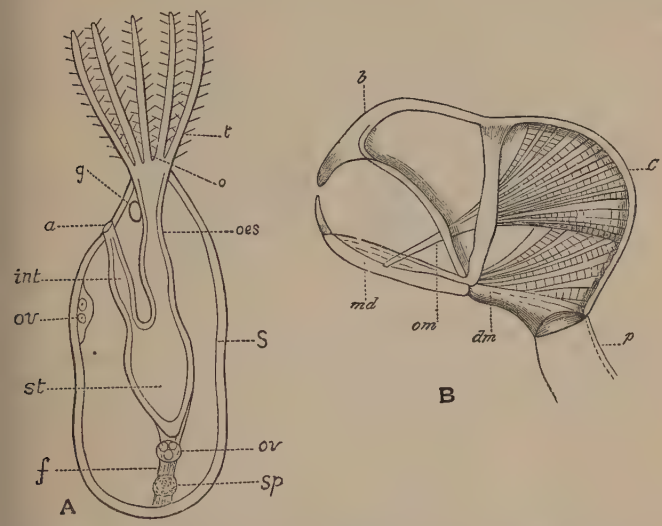


FIG. 65. *A*, Diagram of the structure of a single Polyzoan individual. *s*, body-wall; *t*, tentacles; *o*, mouth; *œs*, œsophagus; *st*, stomach; *int*, intestine; *a*, anus; *g*, ganglion; *f*, funiculus; *ov*, ovary; *sp*, testis. *B*, Avicularium of *Bugula*, enlarged. *b*, beak; *md*, mandible; *C*, chamber; *p*, peduncle; *om*, occlusor muscles; *dm*, divaricator muscles. (After Hincks, Brit. Mar. Polyz.)

de of the œsophagus facing the intestine. The polyzoan ultiplies by budding and sexually, and is generally ermaphrodite. Blood-vessels are absent.

The structures described above form together what known as the *polypide*; this is contained in the body-all or *zoœcium*. The outer layer of the zoœcium nerally becomes hardened by calcareous or chitinous atter, and after the death of the animal this alone mains. The anterior part of the polypide can be

withdrawn by means of longitudinal muscles into the zoœcium, just as the finger of a glove can be pulled into the hand. In some Polyzoa (the Cyclostomata,

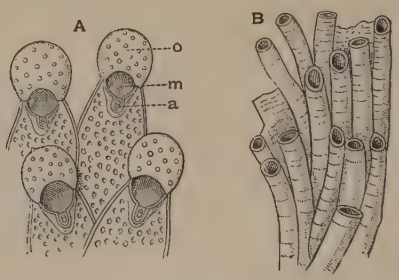


Fig. 66. *A*, Portion of *Smittia landsborovi*, a Cheilostomatous Polyzoan, Recent. *o*, oœcium; *m*, aperture of the cell; *a*, avicularium. *B*, Portion of *Tubulipora fimbria*, a Cyclostomatous Polyzoan, Recent. Enlarged.

fig. 66 *B*) the zoœcium is tube-like, the aperture is at the end and is of the same diameter, or nearly so, as the rest of the tube. In others (the Cheilostomata, fig. 66 *A*) the zoœcium is more or less oval, the aperture (*m*) is contracted and is not terminal, but is situated in front near the anterior end, and is provided with a movable lid or operculum. In many of the Cheilostomata there is at the anterior end of the zoœcium, above the aperture, a projecting chamber (*o*), into which the ova pass, termed the *oœcium*. In many of the Cheilostomata some of the individuals are modified so as to form appendages termed *avicularia* and *vibracula*, but these are rarely preserved fossil. The avicularium (fig. 65 *B*) may be sessile or placed on a peduncle (*p*), and in the more specialized forms has somewhat the appearance of a bird's head, consisting of a chamber (*C*) produced into a beak and provided with a mandible (*md*) which is kept constantly snapping by

means of muscles in the chamber. The vibraculum consists of a long seta kept in motion by means of muscles at its base. The individuals of a colony may communicate with one another, either directly, or by means of *communication-plates*; these are portions of the zoœcium, which are thinner and perforated. The surface of the zoœcium may be smooth or punctate, or ornamented with spines, granules, or ribs.

The Polyzoa are divided into two sub-classes, (1) Ectoprocta, (2) Entoprocta. The Ectoprocta only are found fossil.

SUB-CLASS I. ECTOPROCTA.

The anal aperture is not placed within the area of the lophophore. There are two orders, (1) Phylactolæma, (2) Gymnolæma.

ORDER I. PHYLACTOLÆMA.

The lophophore is horseshoe shaped. There is a tongue-shaped lobe in front of the mouth, known as the epistome. The forms included in this order are found only in fresh-water and do not occur fossil.

ORDER II. GYMNOLÆMA.

The lophophore is circular, and there is no epistome. There are three sub-orders, (1) Cyclostomata, (2) Cheilostomata, (3) Ctenostomata. The last is not known in the fossil state.

SUB-ORDER I. CYCLOSTOMATA.

The zoœcia are calcareous and tubular, their apertures are round and terminal, not constricted and not provided

with opercula. Vibracula are absent, and generally also avicularia and oœcia.

Fenestella. Zoarium funnel-shaped or fan-shaped. Branches straight, united by cross-bars, so as to form a network. The cross-bars do not bear zoœcia. On each branch there is a median ridge or carina, on the sides of which the zoœcia occur. Openings of zoœcia round. Silurian to Permian. Ex. *F. pleibeia*, Carboniferous.

Fascicularia. Zoarium large, generally massive and globose. Zoœcia in the form of long tubes, with horizontal tabulæ, in contact laterally, and forming bundles which are either distinct and radiate from the base to the periphery or fuse into laminæ which intersect. Coralline Crag. Ex. *F. aurantium.*

SUB-ORDER II. CHEILOSTOMATA.

The zoœcia are calcareous and more or less oval, never tubular; their apertures are contracted and provided with a movable operculum. Avicularia, vibracula, and oœcia are often present.

Membranipora. Zoarium encrusting, generally irregular in form. Zoœcia quincuncial, or arranged irregularly, their margins raised, the anterior part depressed and more or less membranous. Chalk to present day. Ex. *M. bidens*, Coralline Crag.

Distribution of the Polyzoa.

By far the larger number of the Polyzoa are marine; they occur both in shallow and in deep water. The deep-water forms belong mainly to the Cheilostomata, the

enostomata being but poorly represented. The Cyclo-
omata are comparatively rare at the present day, except
the Northern seas.

The earliest Polyzoa occur in the Ordovician rocks.
early all the Palæozoic genera are extinct; they
long mainly to the Cyclostomata. The Cheilostomata
not become abundant before the Cretaceous period;
the Tertiary they are more numerous than the
clostomata. Very many of the Pliocene forms belong
species still living.

The chief genera found in the Palæozoic rocks are
nestella, *Ptilodictya*, and *Glauconome*; in the Jurassic,
omatopora, *Spiropora*, *Berenicea*, and *Idmonea*; in the
etaceous, *Ceriopora*, *Heteropora*, *Stomatopora*, *Mem-
anipora*, and *Eschara*; in the Eocene, *Membranipora*,
monea, and *Hornera*; in the Pliocene, *Membranipora*,
chara, *Hornera*, *Fascicularia*, *Cellepora*, and *Lepralia*.

V. MOLLUSCA.

Classes.	*Orders.*
1. Lamellibranchia.	
2. Gasteropoda	1. Polyplacophora. 2. Prosobranchia. 3. Opisthobranchia. 4. Heteropoda. 5. Pulmonata. 6. Pteropoda.
3. Scaphopoda.	
4. Cephalopoda	1. Nautiloidea. 2. Ammonoidea. 3. Belemnoidea.

THE majority of the mollusks (Oysters, Whelks, Cuttl fish etc.) are marine, but some live on land, others fresh-water. Unlike the worms and arthropods, they a unsegmented animals and bear no appendages. Typical the body is bilaterally symmetrical and there is co sequently a repetition of the same organs on each si But in many gasteropods this symmetry is more or l completely obliterated. From the dorsal surface there a fold of the skin forming what is known as the *mant* this generally secretes a calcareous shell, consisting of o or two pieces. On the ventral surface of the body is t *foot*—a muscular organ used in locomotion. Respirati takes place in most cases by means of gills. A heart

esent and is placed on the dorsal surface; it receives terial blood from the gills. The mouth is situated teriorly, and may or may not be provided with organs of astication; the anus, in typical forms, is posterior. Renal gans (nephridia) are present and communicate with the dy-cavity. The nervous system consists of three main oups of ganglia. Sexual reproduction only occurs; ost forms are unisexual, a few hermaphrodite.

The Mollusca are divided into four classes:—(1) mellibranchia, (2) Gasteropoda, (3) Scaphopoda, (4) phalopoda.

CLASS I. LAMELLIBRANCHIA.

In the lamellibranch as in the brachiopod the shell is nerally calcareous and consists of two valves, but these tead of being dorsal and ventral as in the latter, are ced one on the right, the other on the left side of the dy, and the two are joined together by means of a ge and ligament at the dorsal margin. The interior of shell is lined by a fold of the skin, the *mantle* (fig. 67 which is divided into two lobes, one being placed in h valve. In the middle of the space enclosed by the ntle (the mantle-cavity) is the foot (*b*). This is a erally flattened muscular organ, frequently hatchet-[1] or ughshare-shaped, and is used for crawling, or for bur-ing in sand or mud. Sometimes, as in the case of *gonia*, by means of a rapid movement, it enables the mal to jump to a considerable distance. In the genus *tilus* the foot is very much reduced; in others which e lost the power of locomotion (*e.g. Ostrea*) it is absent

[1] Hence the name *Pelecypoda* used by some authors for this class.

altogether. On the posterior part of the foot there is i
some genera (*e.g. Mytilus, Avicula, Arca*) a gland whic

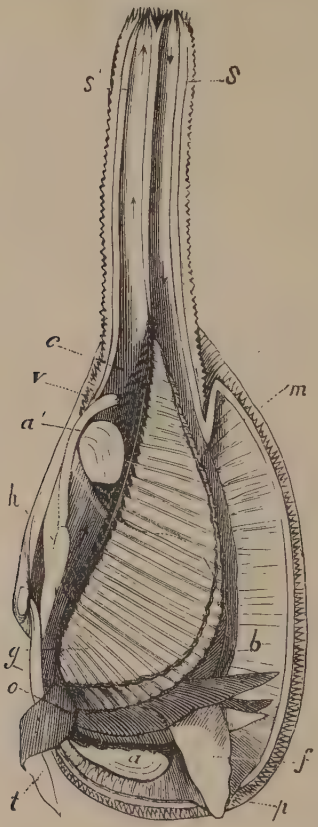


Fig. 67. *Mya arenaria.* The left valve and mantle and half the siphon have been removed. *a*, anterior adductor muscle; *a'*, posteri adductor; *b*, visceral mass; *c*, cloacal chamber into which the an opens; *f*, foot; *g*, branchiæ; *h*, heart; *m*, cut edge of the mantl *o*, mouth; *p*, edge of mantle; *s*, branchial siphon; *s'*, anal siphon *t*, labial palps; *v*, anus. (From Woodward.)

ecretes a bundle of horny fibres, known as the *byssus*, by neans of which the animal moors itself to foreign objects. On each side of the foot, between it and the mantle, and ttached to the body dorsally, are the gills or branchiæ fig. 67 *g*), which are usually leaf-like, whence the name Lamellibranchia.

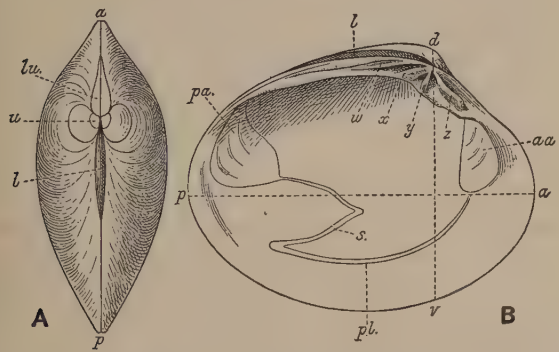
In some forms, the margins of the two mantle-lobes lthough in contact are not united, and when this is the ase, there are usually at the posterior margin two penings leading from the exterior to the mantle-cavity; hese are produced by adjoining excavations or notches in he two lobes of the mantle. A current of water caused y the cilia on the gills and mantle flows in through the entral opening, and provides the animal with food and xygen; another current flows out through the dorsal pening, carrying with it fæcal matters. In many cases, owever, the two lobes of the mantle are fused at one or nore points; the union occurs between the exhalent and nhalent openings, and also, in many forms, ventral to he latter opening. In this way the mantle becomes a ind of bag, having three openings, a ventral for the rotrusion of the foot, and two posterior for the inhalent nd exhalent currents of water. Frequently, at the osterior openings, the mantle is greatly produced so as o form two complete tubes, known as *siphons* (fig. 67 *s*,); these are sometimes free, sometimes united, and may e as much as four times the length of the shell. The entral is generally the longer, it is furnished with tactile apillæ, and is known as the *branchial siphon* (*s*), the orsal being the *anal siphon* (*s'*). In many forms the iphons can be withdrawn into the shell by means of uscles. Occasionally, as in *Teredo*, the siphons are rrounded by a calcareous tube.

The two valves of the shell can be closed by means of the adductor muscles (*a*, *a'*), which pass from the interior of one valve to the other. In many genera there are two adductors, and these forms are frequently spoken of as the *Dimyaria*; others, known as the *Monomyaria*, possess one adductor only, and when this is the case it is the posterior which is present, the anterior having atrophied; this occurs in the oyster, but in this, and in all other forms so far as is known, the anterior muscle is present in the young state.

The mouth (*o*) is placed in the middle line of the body, ventral to the anterior adductor muscle, and is not provided with organs of mastication. At its sides are two leaf-like processes, the *labial palps* (*t*). The mouth leads into a short œsophagus, which passes into a globular stomach surrounded by the liver; next is the intestine which, after undergoing many convolutions, reaches the dorsal surface of the body, where it passes through the pericardium and is surrounded by the ventricle of the heart. The anus (*v*) is situated dorsally to the posterior adductor muscle. In the lamellibranchs there is no head hence the class is sometimes spoken of as the *Acephala*. The nervous system usually consists of three pairs of ganglia. One pair is placed at the sides of the mouth and is connected by nerve-cords with a pair in the foot, and with a third pair placed beneath the posterior adductor muscle. From these ganglia, nerves are given off to the muscles, gills, etc. Tactile organs are present on the margin of the mantle and especially on the ventral siphon. In some forms, eyes occur at the ventral margin of the mantle-lobes, they are especially well-developed in the genus *Pecten*. The heart (*h*) is placed dorsally, just below the hinge and is surrounded by a large pericardial cavity

t consists of two auricles, and a ventricle, which, as lready mentioned, extends round the intestine. The enal organs consist of a pair of glandular bodies under- eath the ventricle. In almost all cases the sexes are eparate, but a few forms are hermaphrodite.

As already mentioned, the two valves of the shell are laced on the sides of the animal. The margin near the inge (fig. 68 *d*) is dorsal, the opposite (*v*), where the



IG. 68. *Cythera chione*. Recent. *A*, dorsal view of the two valves. *B*, interior of left valve. One-half natural size.

a, anterior border; *p*, posterior; *d*, dorsal; *v*, ventral; *lu*, lunule; *u*, umbo; *l*, ligament; *aa*, anterior adductor impression; *pa*, posterior adductor; *pl*, pallial line; *s*, pallial sinus; *w*, *x*, *y*, cardinal teeth; *z*, anterior-lateral tooth.

alves open, is ventral; that near the mouth is anterior (*a*), hat near the anus and siphons posterior (*p*). In the ajority of cases the two valves are equal or almost equal n size, and each valve is generally inequilateral. But in ome (*e.g. Pectunculus*) the shell is equilateral, in others *.g. Ostrea*) it is inequivalve. Each valve may be re- arded as a greatly depressed hollow cone, the apices of hich form the *umbones* (*u*); these are sometimes straight

(*e.g. Pecten*), but generally curved towards the anteri margin; in a few genera (*e.g. Nucula, Trigonia, Exogyr* they are directed posteriorly, and in *Diceras* a spiral. There is sometimes in front of the umbon and bounded by a groove, an oval depressed area (*l* half on each valve; this is termed the *lunule*, and it important to remember that it is always anterior to t umbones. Behind the umbones there is sometimes somewhat similar, but larger, area, known as the *escutcheo*

In the interior of the valves various markings may noticed (fig. 68 *B*), these are produced by the union the muscles with the shell. The adductors form ov round, or sometimes elongated, depressions (the *adduct impressions*, *aa*, *pa*,); in the Dimyaria there are two each valve, one being anterior, the other posterior; in t Monomyaria the posterior only is present. When, as the genus *Mya* etc., the two muscles are placed at equ distances from the hinge-margin, they are of the sa size, since they are equally efficient in closing the valve but in forms like *Mytilus*, where the shell is very inequ lateral and the anterior muscle close to the umbo b the posterior a considerable distance from it, the latter much larger than the former, since it is placed in a mo advantageous position for closing the valves. For t same reason the single muscle of the Monomyaria attached near the centre of the valves. Less importa than the adductor impressions are those produced by t muscles for the movement of the foot, of which there a two in each valve; of these one occurs close to t anterior adductor, the other just above the posteri adductor. Passing from one adductor to the other in ea valve is a linear depression, the *pallial line* (*pl*); this caused by the attachment of the muscles of the mantle

the shell. In some forms this line runs evenly between the two adductor impressions and parallel to the margin of the valve, it is then said to be *simple* or *entire*. But in those genera which possess retractile siphons there is a bending in of the pallial line just before reaching the posterior adductor; this indentation is known as the *pallial sinus* (*s*), and is caused by the muscles of the siphons.

The hinge is formed by projections known as teeth, which alternate in the two valves, the teeth of one valve fitting into depressions between those of the other. Several types of hinge may be recognised:—(1) in which the teeth are numerous and similar in form and size (*e.g. Nucula* (fig. 69 *A*): (2) in which the teeth are few in number and not all of uniform shape and size; some are placed immediately under the umbo and are known as the *cardinal* teeth (fig. 69 *F*), others, termed *laterals*, are placed in front and behind the umbo forming the *anterior-* and *posterior-laterals*; some or all of the cardinals or of the laterals may be absent: (3) in which the teeth are few in number, very thick and striated, *e.g. Trigonia* (fig. 69 *B*, *C*): (4) in which there are two strong teeth of equal size in each valve, which fit into corresponding sockets in the other valve, *e.g. Spondylus* (fig. 69 *D*, *E*): (5) in which the teeth are represented by one or more prominent processes developed in connection with the ligament, *e.g. Mya*: (6) In a few genera (*e.g. Ostrea, Anodonta*) there are no teeth; in some forms this is a primitive character, in others it is the result of degeneration.

The margin of the valve on which the teeth occur is known as the *hinge-line*; generally it is curved, but in some genera like *Arca* it is straight. Sometimes (*e.g. Arca*) there is on each valve, between the hinge-line and

the umbo, a flattened triangular part of the shell, known as the *area*; when this is present the umbones of the two valves are of course widely separated.

In the brachiopods the valves are opened by divaricator muscles, but in the lamellibranchs the work of

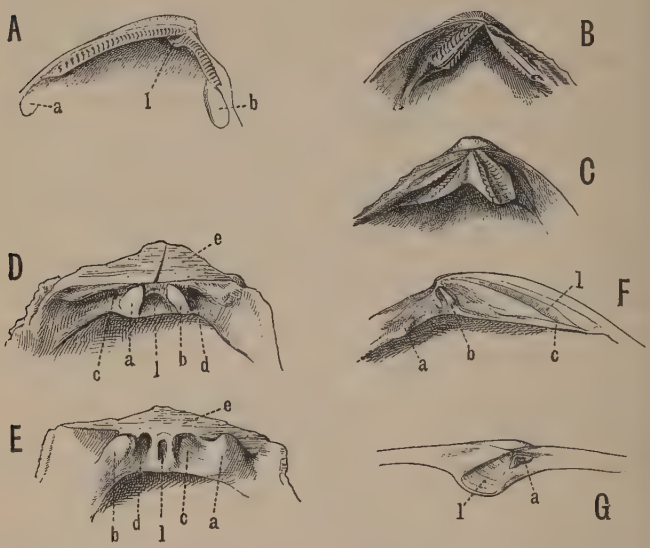


Fig. 69. Some types of hinge. *A*, *Nucula*. *a*, anterior adductor; *b*, posterior adductor; *l*, ligament-pit. *B*, *C*, *Trigonia*. *B*, right valve with two large striated teeth; *C*, left valve with three teeth. *D*, *E*, *Spondylus*; *D*, left valve; *E*, right valve; *a*, *b*, teeth; *c*, *d*, sockets into which the teeth fit; *e*, area; *l*, ligament pit. *F*, *Lucina* (right valve); *a*, anterior-lateral tooth; *b*, cardinal; *c*, posterior-lateral; *l*, ligament. *G*, *Lutraria* (left valve); *a*, strong Λ-shaped cardinal tooth; *l*, process to which the ligament is attached. All drawn from recent specimens.

these muscles is performed by the ligament. This consists of two parts, the external (fig. 68 *l*), and the internal (sometimes erroneously termed the cartilage).

One or other may be absent. The external ligament is composed of horny material and is not elastic; it is usually placed either under the umbones or posterior to them, and is frequently attached to more or less prominent ridges. The internal ligament consists of parallel elastic fibres, and is placed in grooves or sockets along the hinge-line, so that when the valves are closed it is compressed, and being elastic tends to force the valves apart—its action is similar to that of a piece of india-rubber placed in the hinge-line of a door. Consequently in order to open the shell the animal has merely to relax its adductor muscles. Occasionally the ligament is preserved in fossil specimens.

The *length* of a lamellibranch shell is measured from the anterior to the posterior margin (fig. 68 *B*, *a*—*p*), the *breadth* or height from the umbo to the ventral margin (*d*—*v*), the *thickness* from one valve to the other at right angles to the lines of length and breadth.

The shell is secreted by the mantle; its structure varies in different groups. Commonly it consists of two calcareous layers; the inner is the *pearly* or *nacreous* layer, and is formed of numerous thin lamellæ; the outer is the *prismatic* layer (fig. 70), and is composed of prisms placed at right angles to the surface of the shell, each prism being encased in a thin membranous sheath, which can be isolated by dissolving the calcareous part of the shell in acid. The external surface is covered by a green or brownish epidermis. The prismatic layer is formed by the margin of the mantle only, the pearly layer by the whole of the remainder, and this layer gradually encroaches on the former, which consequently cannot afterwards increase in thickness, whereas the pearly layer may do so throughout the life of the animal. The pearly

layer is absent in some forms, and the prismatic structure of the outer layer may be indistinct or altogether wanting and this layer has then a porcellanous appearance. Sometimes the shell consists entirely of aragonite or of calcite in other cases one layer may be of calcite and the other of aragonite.

The surface of the shell may be smooth, or may be ornamented with radiating or concentric ribs, with striæ or spines. Often the exterior shows concentric lamellæ which represent periods of growth. The part of the shell at the umbo is that which is first formed, and it often shows characters different to the other parts. The margins of the valves may be smooth or crenulated; sometimes, as in some species of *Pecten*, the entire shell is corrugated, thus increasing its strength without materially adding to the weight. In many genera the two valves can be completely closed, in others they are always open at some part, and are then said to be *gaping*; this gape occurs most frequently at the posterior end but sometimes also anteriorly.

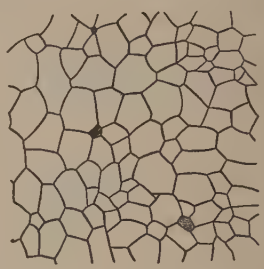


Fig. 70. Section of prismatic layer of recent *Pinna*, parallel to the surface of the shell and at right angles to the prisms. Magnified.

It is of importance to be able to distinguish the right and left valves. In order to do this we must determine first the anterior and posterior margins. When the soft parts of the animal are present this is easily done; but when the shell only is before the observer the points to be noticed are the following:—

(1) The umbones are generally directed anteriorly.

(2) The lunule is always anterior to the umbones.

(3) The external ligament is never entirely anterior.

(4) The pallial sinus is posterior.

(5) When one adductor impression only is present, it is the posterior.

Having found the anterior and posterior margins, the shell should be placed with the dorsal surface uppermost and the anterior margin pointing away from the observer, when the right and left valves will be on his right- and left-hand sides respectively.

Most of the lamellibranchs are free, but a few forms, such as the oyster, are permanently attached by one valve, which is fused to a rock or other object. In some cases the right valve is fixed, in others the left. The shell of these forms becomes irregular and the fixed valve is larger and thicker than the free valve. Other genera are attached by means of a byssus (p. 150), which often passes out through a notch or sinus in one or both valves. In the free forms, movement takes place usually by means of the foot, but some genera (*Pecten, Lima*) move by the rapid opening and shutting of the valves. A few are capable of making borings into various substances; thus *Teredo*, the ship-worm, bores into wood, *Lithodomus* and *Saxicava* into limestone, and *Pholas* into various materials, such as sandstone, limestone, gneiss, peat, and amber. Wood perforated by *Teredo* has been found fossil in various formations of Eocene and Oligocene age.

The features which more especially characterise the Lamellibranchs as a class are, the bilateral symmetry, the division of the mantle into two lobes, the bivalve shell, the lamellar gills, and the absence of a head and of organs of

mastication. Although at first sight the shell appears t resemble closely that of the brachiopods, it differs i several important respects, namely, (1) in the valves bein right and left, instead of dorsal and ventral, (2) in bein generally inequilateral and equivalve, (3) in the presenc of teeth on both valves, (4) in the presence of a ligamen (5) in the umbones never being perforated for a peduncle

Various classifications of the Lamellibranchia have bee from time to time, proposed. By Lamarck this class wa divided into the *Monomyaria* and the *Dimyaria*, dependin on the presence of *one* or *two* adductor muscles. Betwee these two groups, however, there are numerous inte mediate forms in which the anterior muscle is smalle than the posterior; for these a third division, the *Heter myaria*, was established, but its limits are not well define and moreover, in one genus (*Mytilus*) it is found tha whilst some species (*e.g. M. edulis*) have both muscle present, in the closely allied *M. latus*, the anterior addu tor is absent. Another classification, which has bee widely adopted, was suggested by S. P. Woodward, an was based on the presence or absence of siphons; the tw groups being termed the *Siphonida* and the *Asiphonida* the former was further divided according as to whether th pallial line was entire (*Integripalliata*) or was provide with a sinus (*Sinupalliata*). Neumayr, Dall, and othe have founded groups on the character of the hinge; som of the chief variations in this structure have already bee described (p. 155). More recently the classification brough forward by Pelseneer, which is based on the form an structure of the gills, has met with considerable favou but since this can only be applied in the case of gene which have living representatives, its details need not b given here. In the present work no division of th

Lamellibranchia will be attempted; but the genera will be arranged, as far as possible, according to their affinities.

Nucula[1] (fig. 69 *A*). Shell equivalve, trigonal or oval, closed, posterior side very short; umbones directed posteriorly. Surface smooth or ornamented. Interior nacreous. Margins of valves smooth or crenulated. Hinge-line angular, with a median internal triangular ligament-pit, and numerous sharp teeth. Adductor impressions nearly equal. Pallial line simple. Silurian to present day. Ex. *N. hammeri*, Lias; *N. dixoni*, Bracklesham Beds.

Leda. Similar to *Nucula*. Posteriorly the shell is produced and pointed, and provided with a ridge or carina. Pallial line slightly sinuated. Margins smooth. Lunule lanceolate. Silurian to present day. Ex. *L. lachryma*, Inferior Oolite to Cornbrash; *L. caudata*, Pliocene to present day.

Ctenodonta. Shell oval or elongated, nearly equilateral, smooth or with concentric striæ. Ligament external. No area. Hinge-line curved or angular, with numerous teeth, which are smaller at the centre. No internal ligament-pit. Pallial line simple. Cambrian to Carboniferous. Ex. *C. pectunculoides*, Ordovician.

Arca. Shell thick, generally equivalve, sub-quadrangular, ventricose, ornamented with radiating ribs and concentric striæ; margins smooth or dentate; closed or gaping ventrally. Hinge-line straight. Teeth numerous, equal, transverse. Umbones prominent, remote, separated by a lozenge-shaped area, which has numerous ligamental grooves converging from the hinge-margins to the umbones. Adductor impressions sub-equal, the anterior rounded, the

[1] All the genera of mollusca described are marine unless otherwise stated.

posterior divided. Pallial line simple. Ordovician t present day. Ex. *A. tetragona*, Pliocene to present day *A. granosa*, Recent.

Cucullæa. Shell similar to *Arca*. Hinge with shor central transverse teeth, and two to five lateral teet nearly parallel to the hinge-margin. Posterior adducto fixed to a thin raised plate. Jurassic to present day Ex. *C. fibrosa*, Blackdown Greensand.

Pectunculus (= *Axinæa*). Shell thick, solid, sub orbicular, equivalve, almost equilateral. Surface smoot or radially striated. Ligament external. Umbone central, slightly curved, separated by a triangular are provided with diverging grooves for the ligament. Hing with a semicircular row of numerous, small, strong transverse teeth, obliterated at the centre in the olde forms by the growth of the area. Margins crenulat inside; adductor impressions sub-equal. Pallial lin simple. Cretaceous to present day. Ex. *P. glycimeri* Coralline Crag to present day.

Cardiola[1]. Shell thin, convex, oval, generally inequ lateral; umbones prominent, incurved. Surface wit well-marked radiating and concentric grooves. Hinge-lin straight, probably with very small teeth; ligamental are large, horizontally grooved. Muscular impressions u known. Silurian and Devonian. Ex. *C. interrupta*, Low Ludlow etc.

Trigonia (fig. 69 *B*, *C*). Shell thick, ornamente with rows of tubercles or with radiating or concentric rib trigonal, very inequilateral, anterior margin rounde

[1] The affinities of *Cardiola* have not been satisfactorily determine some authors consider that it is related to *Cardium*.

posterior produced and angular. Generally with a ridge extending from the umbones to the posterior border, cutting off a portion which has a different ornamentation. Umbones anterior, directed posteriorly. Cardinal teeth diverging, striated, two in the right valve, three in the left, the central tooth in the latter being bifid. Ligament marginal, thick. Adductor impressions deep, the anterior smaller than the posterior, and placed near the umbones. A pedal impression in front of the posterior adductor of each valve and also one in the umbo of the left valve. Pallial line simple. Interior nacreous. Lias to present day. Ex. *T. costata*, Inferior Oolite to Corallian; *T. clavellata*, Corallian.

Schizodus. Similar to *Trigonia*; shell thin and smooth, umbones placed anteriorly; anterior adductor impression faintly marked. Carboniferous and Permian. Ex. *S. obscurus*, Permian.

Anomia. Shell thin, irregular or sub-circular, attached by a calcified byssus, which passes through a rounded sinus near the umbo of the right valve. Right valve flattened, with a central adductor impression; left valve larger, convex, with three impressions of the byssal muscles and one of the adductor. Teeth absent. Lias to present day. Ex. *A. ephippium*, Pliocene to present day.

Mytilus. Shell equivalve, inequilateral, elongated, sub-triangular, posterior border rounded. Umbones sharp, terminal, anterior. Teeth small or absent. Ligament linear, marginal, sub-internal. Anterior adductor impression small, placed near the umbo; posterior large. Surface of shell with an epidermis. Trias to present day. Ex. *M. sublævis*, Great Oolite; *M. edulis*, Pliocene to present day.

Modiola. Shell similar to *Mytilus*, but oblong inflated in front. Umbones obtuse, anterior, but not terminal. Devonian to present day. Ex. *M. modiolus* Recent; *M. imbricata*, Inferior Oolite to Kellaways Rock.

Lithodomus. Shell similar to *Modiola*; sub-cylindrical, rounded in front, wedge-like behind. Carboniferous to present day. Ex. *L. inclusus*, Inferior Oolite to Corallian.

Pinna. Shell equivalve, inequilateral, wedge-shaped generally thin, without ears. Umbones sharp, anterior terminal. Valves gaping posteriorly. Hinge-line straight long. No teeth. Ligament linear, almost entirely internal, lodged in a groove. Posterior adductor large sub-central; anterior apical. Devonian to present day Ex. *P. hartmanni*, Lias; *P. affinis*, London Clay.

Gervillia. Shell obliquely elongated, very inequilateral, slightly inequivalve, the left valve a little more convex than the right; umbones almost terminal. Hinge-line straight, broad, with numerous perpendicular, widely separated ligament-pits; its posterior edge with two or more obscure teeth. Ears not very distinct from the rest of the shell, the anterior very short, the posterior long. Adductor impressions as in *Avicula*. Trias to Eocene. Ex. *G. anceps*, Lower Greensand.

Inoceramus. Shell variable in form, circular, ovate or oblong; inequilateral, inequivalve, ventricose or compressed, without ears. Umbones prominent. No teeth. Surface with concentric (or rarely radiating) grooves. Hinge-line straight, long, with numerous parallel, close-set transverse ligament-pits. Adductor impression rarely visible. Inner layer of shell thin and nacreous, outer

layer thick, formed of prismatic fibres. Lias to Chalk. Ex. *I. concentricus*, Gault; *I. brongniarti*, Chalk.

Perna. Shell nearly equivalve, inequilateral, compressed, sub-quadrate or sub-circular, with ears. Hinge-line straight, without teeth. Hinge-area broad, with numerous transverse, elongated ligament-pits placed close together and parallel to one another. Right valve with a byssal sinus. Adductor impression large, sub-central, double. Posterior ear often large, anterior rudimentary. Trias to present day. Ex. *P. mulleti*, Lower Greensand.

Avicula. Shell oblique, inequilateral, inequivalve, left valve more convex than the right. Interior nacreous. Hinge long, straight, with one or two small cardinal teeth and a lamellar lateral tooth. Posterior ear wing-like and longer than the anterior. A byssal sinus under the right anterior ear. Hinge-area small. Ligament partly internal, partly external, in a groove. Posterior adductor impression large, sub-central. Silurian to present day. Ex. *A. media*, Barton Beds etc.

Pseudomonotis. Similar to *Avicula*, but the shell is oval, the left valve large and very convex, and the right valve flattened; the anterior ear small or rudimentary. Devonian to Cretaceous. Ex. *P. echinata*, Cornbrash.

Pterinea. Shell equivalve; form similar to *Avicula*. Hinge with anterior small teeth, and posterior laminar teeth. Hinge-area large, longitudinally striated. Posterior adductor impression large, shallow; anterior impression small, deep, below the anterior ear. Ordovician to Carboniferous. Ex. *P. lævis*, Devonian.

Posidonomya. Shell thin, oblique, oval, equivalve, compressed, with concentric furrows. Umbones small, sub-central. Hinge-line straight, short, without teeth, without ears. Silurian to Jurassic. Ex. *P. becheri*, Carboniferous.

Aviculopecten. Shell somewhat inequilateral; right valve less convex than the left. Hinge-line straight, anterior ear smaller than the posterior; a byssal sinus beneath the anterior ear in the right valve. Ligament in narrow grooves parallel to the hinge-line. Adductor impression large, sub-central. Surface usually radially ribbed. Devonian to Permian. Ex. *A. papyraceus*, Carboniferous.

Ostrea. Shell with lamellar structure, irregular, inequivalve, slightly inequilateral, fixed by the left and larger valve. Left valve convex, often with radiating ribs or striæ; umbo prominent, sometimes directed anteriorly, sometimes posteriorly. Right valve flat or concave, often smooth. Ligamental cavity triangular or elongated. Hinge without teeth. Adductor impression sub-central; pallial line indistinct. Trias to present day. Ex. *O. deltoidea*, Kimeridge Clay; *O. edulis*, Pliocene and Recent.

Alectryonia. Similar to *Ostrea*. Both valves with coarse angular folds; edges of valves toothed. Trias to present day. Ex. *A. gregaria*, Corallian; *A. frons*, Lower Chalk.

Gryphæa. Shell similar to *Ostrea*, but free in the adult stage; left valve large and convex, with a prominent incurved umbo. Right valve flattened or concave. Lias to present day. Ex. *G. incurva*, Lias.

Exogyra. Similar to *Ostrea*. Shell fixed by the left (larger) valve. Right valve flat, resembling an operculum. Umbones more or less spiral, directed posteriorly. Upper Jurassic to Chalk. Ex. *E. columba*, Upper Greensand.

Chlamys. Shell sub-circular or trigonal, closed, almost equilateral, nearly equivalve. Surface with radiating ribs or striæ. Hinge-line straight; anterior ears longer than the posterior and with a sinus for the byssus on the right valve. Ligament-pit central, and triangular. Adductor impression large, a little excentral. Trias to present day. Ex. *C. asper*, Upper Greensand; *C. islandica*, Pleistocene and Recent.

Hinnites. The young shell is like *Chlamys*; the adult is irregular like *Ostrea*, and is attached by the right valve. Trias to present day. Ex. *H. abjectus*, Inferior Oolite to Corallian.

Pecten. Similar to *Chlamys*. Right valve very convex, left flattened. Ears nearly equal. No byssal sinus. Cretaceous to present day. Ex. *P. maximus*, Pliocene to present day.

Lima. Shell obliquely oval, equivalve, compressed, with radiating striæ or ribs. Valves gaping anteriorly and sometimes posteriorly. Umbones distant, sharp. Hinge-line straight without teeth, with ears; the ears unequal. On each valve a triangular hinge-area, with a central ligament-pit. Adductor impression large, excentral. Two small pedal impressions. Carboniferous to present day. Ex. *L. gigantea*, Lias; *L. cardiiformis*, Lower Oolites.

Spondylus (fig. 69 *D*, *E*). Shell irregular, with ears,

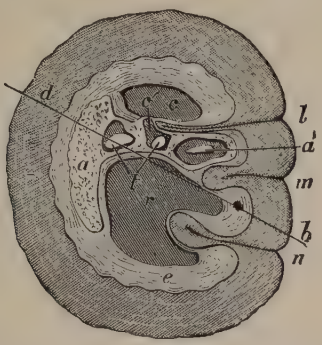
attached by the right valve; surface with radiating ribs which are spiny or foliaceous. Right valve larger (more convex) than the left, with a triangular hinge-area. Two strong teeth in each valve, which fit into corresponding sockets in the other valve; between the teeth a triangular ligament-pit; ligament partly external. Adductor impression large, sub-central. Jurassic to present day. Ex. *S. rarispina*, Bracklesham Beds; *S. gœderopus*, Recent.

Plicatula. Similar to *Spondylus*. Surface smooth, folded or scaly. Without ears. Hinge-area obscure. Ligament internal. Adductor excentral. Trias to present day. Ex. *P. spinosa*, Lias; *P. inflata*, Chalk.

Chama. Shell irregular, thick, inequivalve, fixed by the umbo of the larger valve (generally the left, sometimes the right). Umbones spiral or sub-spiral, directed anteriorly, that of the fixed valve longer than the other. Surface with concentric lamellæ or spines. The fixed valve larger and much deeper than the other. In each valve a strong cardinal tooth, and sometimes in the inferior valve a narrow curved posterior tooth also. Ligament external, in a deep groove, prolonged towards the umbones. Adductor impressions large, the anterior commencing near the hinge-line. Pallial line simple. Upper Cretaceous to present day. Ex. *C. squamosa*, Barton Beds.

Hippurites (fig. 71). Shell very large and massive, conical or sub-cylindrical, very inequivalve, fixed by the apex of the larger valve. The larger (right) valve conical, striated or smooth, and with three parallel furrows on the cardinal side, and three corresponding folds in the interior; one small cardinal tooth; two adductor im-

ressions, the anterior being very large. Smaller (left) alve flattened or slightly convex, operculiform, porous,



g. 71. Transverse section of the large valve of *Hippurites cornu-vaccinum*. *r*, umbonal cavity; *e*, internal layer of shell; *d*, external layer; *l*, *m*, *n*, folds; *t*, cardinal teeth; *a*, anterior adductor; *a'*, posterior adductor; *c*, cavity; *c'*, cardinal fossa. Cretaceous. (From Woodward.) Reduced.

ie pores leading into canals; with a central umbo and vo prominent cardinal teeth, the anterior very large, the osterior smaller. The smaller valve is formed of two yers, the outer is thin and prismatic, the inner is porcel-nous and traversed by numerous canals. The larger lve is also composed of two layers, the outer is formed small prisms arranged in parallel layers obliquely to the rface of the shell, the inner is porcellanous, and formed thin leaflets. Middle and Upper Cretaceous. Ex. *H. rnu-vaccinum*.

Cardium. Shell convex, nearly equilateral, cordate oval, generally closed. Umbones prominent, incurved, rned slightly to the anterior side. Surface with radiating os, which are often spiny. Margins of valves crenulated, vo cardinal teeth, one anterior-lateral, and one poste-

rior-lateral, in each valve. Ligament external. Adducto impressions shallow. Pallial line entire. Trias to presen day. Ex. *C. aculeatum*, Pleistocene and Recent; *C. edule* Pliocene to present day.

Protocardia. Similar to *Cardium*, but only th posterior part of the shell is provided with radiating ribs the remainder with concentric ribs. Jurassic to presen day. Ex. *P. hillana*, Blackdown Greensand.

Conocardium. Shell more or less trigonal, with radiating ribs; anterior side short, truncated, produced int a long tube; posterior side oblique, gaping. Hinge-lin long; with an anterior-lateral and an indistinct cardina tooth. Silurian to Carboniferous. Ex. *C. hibernicum* Carboniferous Limestone.

Venericardia. Shell oval, triangular, or heart-shaped inequilateral, with radiating ribs. Umbones prominent Ventral margin crenulated internally, not sinuous. Liga ment external. Hinge thick; in the right valve tw oblique cardinal teeth and one small anterior-lateral; i the left two diverging cardinal teeth and one elongate posterior-lateral tooth. Adductor impressions unequa Pallial line simple. Cretaceous to present day. Ex. *planicosta*, Bracklesham Beds.

Cardita. Shell oblong, elongated, very inequilatera with prominent scaly ribs; often a little gaping an sinuous at its ventral margin. Lunule present. Ligamen external. In the right valve two long, parallel cardina teeth, and a small anterior-lateral tooth. In the left valv one short cardinal (anterior), and one long cardinal (pos terior), and a rudimentary posterior-lateral tooth. Adducto

mpressions large. Pallial line simple. Trias to present ay. Ex. *C. senilis*, Coralline Crag; *C. calyculata*, Recent.

Astarte. Shell thick, inequilateral, more or less tri-onal or sub-orbicular, compressed, closed. Surface usually ith concentric furrows or striæ. A thick epidermis. Umbones prominent. Lunule distinct. Escutcheon elon-ated. Ligament external. Two cardinal teeth in each alve, lateral teeth rudimentary. Adductor impressions rongly marked; above the anterior one is a pedal im-ression. Pallial line simple. Trias to present day. Ex. . *omalii*, Coralline Crag.

Opis. Shell trigonal, cordiform, convex, with an blique keel extending from the umbo to the posterior order. Umbones prominent, incurved or sub-spiral. unule large and very deep. Surface generally with ncentric furrows. One cardinal tooth in the right valve, vo in the left. Pallial line simple. Trias to Chalk. x. *O. lunulatus*, Inferior Oolite.

Crassatella. Shell solid, oblong or sub-trigonal, tenuated behind. Surface smooth or concentrically rrowed. Margins of valves smooth or crenulated. Um-nes small, close together. Lunule distinct. Ligament ternal, placed in a pit under the umbo. Hinge with vo cardinal teeth, and some small laterals. Adductor mpressions deep. Pallial line simple. Cretaceous to resent day. Ex. *C. sulcata*, Barton Beds.

Hippopodium. Shell very thick, oblong; surface ith lines of growth. Umbones large, anterior. Hinge ick, with one oblique tooth which may disappear in old ecimens. Adductor impressions deep. Pallial line mple. Lias to Great Oolite. Ex. *H. ponderosum*, Lower d Middle Lias.

Cardinia. Shell trigonal, oval, or oblong, very inequi lateral, compressed, thick, marked by lines of growth Interior not nacreous. Umbones small, sharp, close to gether. Ligament external. Cardinal teeth small c obsolete; in the right valve one anterior-lateral tooth, i the left, one posterior-lateral. Impression of anteric adductor very deep. Pallial line simple. Trias to Lowe Oolites. Ex. *C. listeri,* Lias.

Unio. Shell oval or elongated, with a thin epidermis Surface smooth, striated or folded; interior nacreou Umbones more or less anterior, often corroded. Ligamen external, elongated. In the right valve there are tw anterior-lateral teeth and a long lamellar posterior-latera tooth; in the left valve one anterior-lateral, one cardina and two long lamellar posterior-lateral teeth. Adducto impressions very deep, especially the anterior. Pallial lin simple. Purbeck Beds to present day. Lives in fresh water. Ex. *U. littoralis,* Pleistocene and Recent.

Carbonicola (= *Anthracosia*). Similar to *Unio,* bu the anterior part of shell is broad and tumid, the posteric part narrow and compressed; usually a constriction at th ventral border. With or without cardinal teeth, no lateral Hinge-plate triangular. Anterior adductor large, near th margin. Pedal impression above the anterior adducto Carboniferous and Permian. Probably freshwater. E *C. robusta,* Coal Measures.

Anthracomya. Differs from the preceding chief in having the posterior part of the shell broad an expanded. Carboniferous. Ex. *A. adamsi.*

Arctica (= *Cyprina*). Shell orbicular or oval, conve with concentric striæ and a thick epidermis. Umbon

prominent, incurved. Ligament external, prominent. No unule. In each valve two cardinal teeth and two or three aterals. Adductor impressions oval. Pallial line entire. Margins of valves smooth. Lias to present day. Ex. *C. slandica*, Coralline Crag to present day.

Isocardia. Allied to *Arctica*. Umbones inflated, urved anteriorly or spirally inrolled. In each valve wo nearly parallel cardinal teeth and one posterior-lateral. urassic to present day. Ex. *I. cor*, Coralline Crag to resent day.

Lucina (fig. 69 *F*). Shell orbicular or oval, slightly nequilateral. Lunule distinct. An oblique furrow exends from the umbo to the posterior border. Hinge with sually two cardinal teeth and one or two lateral in each alve; the lateral and sometimes the cardinal are absent. igament elongated, external, sometimes partly internal. dductor impressions well-marked, the anterior elongated nd placed mainly within the pallial line, the posterior val. Pallial line entire. Margins of valves smooth or nely crenulated. Trias to present day. Ex. *L. borealis*, oralline Crag to present day.

Cyrena. Shell cordiform, oval, or trigonal; umbones ften corroded. Hinge with three cardinal teeth; one nterior- and one posterior-lateral in the left valve, and wo of each in the right valve. Ligament prominent, xternal. Pallial line usually entire. Lias to present ay. Lives in fresh and brackish water. Ex. *C. semiriata*, Hamstead Beds.

Corbicula. Similar to *Cyrena*, but with the lateral eeth lamellar and finely striated. Eocene to present day. x. Freshwater. *C. fluminalis*, Pliocene to present day.

Venus. Shell thick, oval, inflated; surface smooth, with ribs or concentric lamellæ; lunule distinct. Margin of valves finely crenulate. Hinge-plate wide, with thre cardinal teeth, often bifid. Ligament external, prominen Pallial sinus small. Middle Jurassic to present day. E *V. casina*, Pliocene to present day.

Cytherea (= *Meretrix*) (fig. 68). Shell thick, ovat sub-trigonal, smooth or with concentric striæ. Margins valves not crenulate. Lunule well-marked. Ligamen external. Hinge thick, with three cardinal teeth in eac valve, two anterior-lateral in the right, and one in the le valve. Pallial sinus angular. Jurassic to present da Ex. *C. incrassata*, Headon Beds.

Dosinia (= *Artemis*). Shell orbicular, compresse with concentric striæ. Lunule depressed. Escutche narrow. Ligament sunk. Three cardinal teeth in eac valve, one anterior-lateral in the left valve, and tw (rudimentary) in the right. Margins smooth. Palli sinus very deep. Upper Cretaceous to present day. E *D. exoleta*, Coralline Crag to present day.

Tellina. Shell oval, transversely-elongate, or sub orbicular, slightly inequivalve, compressed, rounded i front, attenuated behind, and furnished with an obliqu fold from the umbo to the posterior border. Margins valves smooth. Two cardinal teeth in each valve, an one anterior- and one posterior-lateral, which are ofte indistinct in the left valve. Ligament external, prom nent. Pallial sinus very deep. Jurassic to present da Ex. *T. balthica*, Pliocene to present day.

Mactra. Shell oval or trigonal, nearly equilater slightly gaping behind, smooth or with concentric stri

nternal ligament in a large triangular pit. External igament in a groove. In front of the internal ligament-it is a bifid cardinal tooth (in the form of an inverted V); anterior- and posterior-lateral teeth well-marked, com-pressed. Adductor impressions semicircular. Pallial sinus round or angular. Cretaceous to present day. Ex. *M. valis*, Red Crag to present day.

Solen. Shell very long, sub-cylindrical, straight, mooth or finely striated, the dorsal and ventral margins arallel; gaping at both extremities. Margins of valves mooth. Umbones at the anterior end. Hinge terminal, ith one cardinal tooth in each valve. Ligament long, xternal. Anterior adductor impression elongated, parallel o the dorsal margin. Pallial sinus short. Eocene (perhaps arlier) to present day. Ex. *S. obliquus*, Bracklesham eds; *S. vagina*, Recent.

Mya. Shell oblong, gaping at both ends, particularly t the posterior; the left valve a little smaller than the ght. In the right valve one small cardinal tooth; in ne left valve a large spoon-like process to which the nternal ligament is fixed. Anterior adductor impression ongated. Pallial sinus large and rounded. Eocene to resent day. Ex. *M. truncata*, Coralline Crag to present ay.

Corbula. Shell oval, inequivalve, closed, rounded in ont, somewhat angular and contracted behind. Surface nerally with concentric grooves. Umbones prominent. ight valve larger and more convex than the left, and ith a strong cardinal tooth in front of the ligament-t, and also a posterior cardinal tooth. Adductor im-essions well-marked. Pallial sinus very small. Trias present day. Ex. *C. ficus*, Barton Beds.

Glycimeris (= *Panopea*). Shell equivalve, inequi lateral, oblong, thick, concentrically striated, gaping a each end, especially at the posterior. Ligament externa on a prominent ridge. One strong cardinal tooth in eac valve. Pallial sinus very deep. Cretaceous to presen day. Ex. *G. faujasi*, Coralline Crag to present day.

Saxicava. Shell small, more or less oblong, gaping umbones anterior. Ligament external. Teeth absent, c one or two cardinals present. Pallial line not continuou Jurassic to present day. Ex. *S. rugosa*, Coralline Crag t present day.

Ceromya. Shell heart-shaped, inflated, finely gran ular, with concentric grooves. Left valve not quite s convex as the right. Anterior side short, posterior longe and compressed. Umbones prominent, anterior, curve forward. Hinge thickened, with a ridge behind the um bones; teeth absent. Pallial line sinuous. Jurassic. Ex *C. concentrica*, Inferior Oolite to Cornbrash.

Arcomya (= *Myacites*). Shell thin, oblong, inequi lateral, ventricose, gaping at the ends; surface with gran ules and often with concentric furrows. Umbones smal close together. Ligament external. Hinge without teeth Adductor impressions faint. Pallial line sinuous. Tria to Chalk. Ex. *A. elongata*, Lias.

Pleuromya. Shell transversely elongated, anteri side short, posterior long and generally compressed, some times gaping; surface with concentric folds. Adducto impressions faintly marked; pallial sinus deep. Hing without teeth. Trias to Cretaceous. Ex. *P. donacin* Corallian and Kimeridge Clay.

Goniomya. Similar to *Arcomya*, but with V-shape

ribs pointing ventrally. Lias to Cretaceous. Ex. *G. literata*, Inferior Oolite to Corallian.

Pholadomya. Shell thin, translucent, oblong or oval, ventricose, equivalve, gaping posteriorly and sometimes anteriorly. Anterior side short and rounded. Surface with radiating ribs crossed by concentric striæ. Umbones prominent. Ligament external. Hinge without teeth or with a small transverse tubercle. Adductor impressions very faint. Pallial sinus deep. Lias to present day. Ex. *P. margaritacea*, London Clay.

Thracia. Shell oblong, compressed, attenuated and gaping posteriorly; surface smooth or concentrically striated. Umbones turned a little to the posterior side. Right valve larger than the left. Hinge with a stout calcareous process or ossicle in each valve. External ligament short and prominent. Adductor impressions small. Pallial sinus not very deep. Trias to present day. Ex. *T. rubescens*, Coralline Crag to present day.

Pholas. Shell elongate, cylindrical, gaping at both ends. Surface with spiny ridges, best marked in front. On the dorsal region are one or more calcareous plates. No teeth; no ligament. In the interior, under the umbones, is a process for the insertion of the muscle of the foot. Pallial sinus very deep. Lias to present day. Ex. *P. cylindrica*, Red Crag; *P. dactylus*, Recent.

Teredo. Shell more or less globular, gaping at the ends, valves tri-lobed, with concentric striæ. In the interior, under the umbones, is a long narrow plate for the insertion of the pedal muscle. Posterior part covered by a long, calcareous tube, which is sub-cylindrical, straight or curved, and often with partitions. Jurassic to present day. Ex. *T. norvegica*, Coralline Crag to present day.

Distribution of the Lamellibranchia.

All the Lamellibranchs are aquatic animals, and by far the larger number are marine. The marine forms range from the shore-line down to a depth of 2900 fathoms; they are most abundant in shallow water, and are scarce at depths greater than 500 fathoms.

In England the Lamellibranchs appear first in the Tremadoc Beds; they gradually increase in importance, and attain their maximum at the present day. Many of the genera have a rather extended range in time.

The most important genera in the different systems are as follows:

Cambrian. *Ctenodonta, Glyptarca, Modiolopsis.*

Ordovician. *Ctenodonta, Palæarca, Ambonychia, Modiolopsis.*

Silurian. *Ctenodonta, Cardiola, Avicula, Pterinea, Modiolopsis, Grammysia.*

Devonian. *Ctenodonta, Cardiola, Pterinea, Aviculopecten, Actinopteria, Megalodon, Conocardium.*

Carboniferous. *Aviculopecten, Posidonomya, Pinna, Conocardium, Carbonicola* (=*Anthracosia*), *Anthracomya, Edmondia, Sanguinolites.*

Permian. *Bakevellia, Schizodus.*

Trias. *Nucula, Arca, Myophoria, Gervillia, Ostrea, Chlamys, Lima, Cardium, Cardita.*

Jurassic. *Nucula, Arca, Macrodon, Trigonia, Modiola, Hippopodium, Avicula, Pseudomonotis, Gervillia, Perna, Ceromya, Pinna, Ostrea, Gryphæa, Alectryonia, Chlamys, Hinnites, Lima, Cardium, Unicardium, Astarte, Opis, Pachyrisma, Cardinia, Arcomya, Pleuromya, Pholadomya, Thracia.*

Cretaceous. *Nucula, Cucullæa, Trigonia, Gervillia, Inoceramus, Perna, Ostrea, Exogyra, Alectryonia, Chlamys, Neithea, Lima, Spondylus, Plicatula, Hippurites, Radiolites, Cardium, Protocardia, Pholadomya.*

Eocene. *Nucula*, *Pectunculus*, *Chlamys*, *Pecten*, *Chama*, *Cardium*, *Venericardia*, *Cardita*, *Astarte*, *Arctica* (=*Cyprina*), *Lucina*, *Cytherea*, *Glycimeris* (=*Panopæa*), *Pholadomya*.

Oligocene. *Mytilus*, *Dreissensia*, *Ostrea*, *Cyrena*, *Corbula*, *Potamomya*, *Cytherea*, *Psammobia*.

Pliocene. *Nucula*, *Pectunculus*, *Mytilus*, *Chlamys*, *Pecten*, *Cardium*, *Cardita*, *Astarte*, *Arctica* (=*Cyprina*), *Isocardia*, *Lucina*, *Venus*, *Artemis*, *Tellina*, *Mya*.

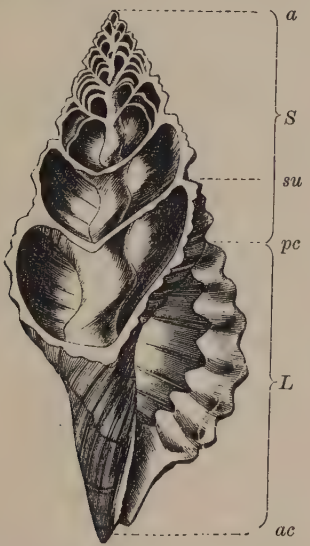
CLASS II. GASTEROPODA.

The Gasteropoda contain even a larger number of forms than the preceding class; well-known examples are the snail, the whelk, and the cowry. The bilateral symmetry, so characteristic of the lamellibranchs, is generally to a large extent obliterated, owing to the twisting of the visceral-sac and the atrophy of some of the organs on one side of the body. There is a distinct head, which bears tentacles, and usually also eyes. On the ventral surface of the body is the foot; this is usually large and sole-like and used for crawling, but in the Heteropods it is in the form of a flattened fin, and in the Pteropods it is wing-like. The mantle is never divided into two lobes. Respiration takes place in some cases through the skin, but generally by means of a lung-cavity or by gills; the latter are placed in a sac formed by the mantle; sometimes they are present on both sides of the body, but very often the original left gill has disappeared. In some forms the mantle at the opening of the gill-sac is produced into a tube, known as the *siphon*, by means of which water passes to the gills. The mouth is at the anterior end of the body; the anus is occasionally posterior, but as a rule it is placed near the opening of

the gill chamber. Just within the mouth on the floor of the cavity is a dental apparatus, known as the *odontophore*; this consists of a chitinous ribbon, on which numerous teeth are placed in rows and it serves as a rasping organ. The arrangement of the teeth varies in different genera and is of considerable importance in classification but since the odontophore has never been definitely recognised in the fossil forms, it can only be used by the palæontologist in the case of genera which have existing representatives. The nervous system consists of ganglia and nerve-cords, the arrangement of which varies in different groups. Some of the gasteropods are unisexual, others hermaphrodite.

In the majority of the gasteropods a shell is secreted by the mantle; in a few forms, as for instance the slugs, it is internal, but usually it is external and covers the visceral mass. The shell, except in *Chiton* and its allies, consists of a single piece, and is hence said to be *univalve*. In the limpet (*Patella*) it has the form of a hollow cone; but in most cases it consists of a long tube, open at one end, and tapering to a point at the other. This tube is generally coiled into a spiral, each coil being termed a *whorl*; in a few genera (*e.g. Vermetus, Siliquaria*) the whorls are separated, but as a rule they are in contact (fig. 72), the line between two contiguous whorls being known as the *suture* (*su*). All the whorls, except the last one, together form the *spire* (*S*) of the shell, the point of which is termed the *apex* (*a*). The last whorl is nearly always larger than the preceding, frequently very much so, and the part of it farthest from the apex forms the *base* of the shell. The form of the spire varies in different genera and species, sometimes it is composed of a large number of whorls, sometimes of few, and it may be long

short, or depressed. The angle of the spire (*spiral angle*) will consequently also vary; this is measured by lines drawn from the apex to the base of the shell on opposite sides of the exterior of the whorls. The coiling of the shell is usually *dextral*; that is, when the apex of the shell is pointed away from the observer (as in fig. 72) the aperture will be on the right-hand side; in a few cases it is *sinistral*, when the aperture will be on the left.



G. 72. Longitudinal section of *Triton corrugatus*. The upper part of the spire has been partitioned off many times successively. *a*, apex; *su*, suture; *S*, spire; *L*, outer lip of the aperture; *ac*, anterior canal; *pc*, posterior canal. (From Woodward.)

Frequently the inner parts of the whorls coalesce, and rm an axial pillar extending from the apex to the base the shell (fig. 72) and known as the *columella*. In her cases the inner parts do not fuse and in the place of

the columella there is left a space, extending from the base of the shell a greater or less distance towards the apex; this space, which opens at the base of the shell, is called the *umbilicus*. When there is a columella the shell is often said to be *imperforate*, when instead there is an umbilicus it is *perforate*; sometimes in the latter case the space becomes partly filled up with a shelly growth, known as *callus*. The animal is attached to the columella by means of a muscle, the contraction of which enables it to withdraw completely into the shell.

Usually the cavity of the gasteropod shell is continuous from the apex to the aperture, but in a few cases partitions are thrown across the earlier parts of the shell (fig. 72), forming chambers which remain empty. The form of the aperture varies considerably in different genera and is of great importance in classification; in shape, it may be circular, oval, elongate oblong, etc. Its margin is termed the *peristome*; the outer part forms the *outer lip* (*L*), the inner part (that next the columella) the *inner lip*. As the gasteropod crawls along, the shell is carried on the dorsal surface of its body with the apex directed backwards; consequently the part of the aperture farthest from the apex is *anterior*, the opposite (nearest the apex) is *posterior*. Sometimes, as in *Natica*, there is no break in the peristome, and it is then said to be entire or *holostomatous*; in others the anterior border is notched or produced into a tube (*ac*) in which the siphon is placed, these forms are said to be *siphonostomatous*; sometimes there is also at the posterior border another canal (*pc*), in which the excurrent or anal siphon is placed. The lip may be thin and sharp, or thickened. Sometimes it is curved outwards, and is then said to be *reflected*; or it is curved in

wards—*inflected.* Its margin may be even, or crenulated, or produced into processes.

In many genera there is attached to the posterior part of the foot a calcareous or horny plate, the *operculum*; this is so arranged that when the animal withdraws into its shell, the operculum closes more or less completely the aperture. It has been considered by some as a second valve, but it probably represents the byssus of the lamellibranch. The operculum is seldom preserved fossil; its form varies considerably in different genera, in some (*Turbo*) it is of very large size; it may be spiral, and is then sometimes formed of a large number of whorls (*multispiral*) as in *Trochus*, or of a few whorls (*paucispiral*) as in *Littorina*. When not spiral it may be *concentric*, when growth is equal all round, and it is marked with concentric lines, the nucleus being nearly central, as in *Paludina*; or it may be *unguiculate* or *claw-shaped* when the nucleus is at the apex as in *Fusus*.

The form of the shell in the spiral gasteropods varies considerably, depending on the arrangement of the whorls in one plane or in a helicoid spiral, on the spiral angle, on the number and shape of the whorls, on the size of the last whorl and whether it conceals the earlier whorls or not; the chief types are the following:—

1. *Discoidal;* the whorls all in one plane, as in *Planorbis.*

2. *Conical* or *trochiform;* conical with a flat base, as in *Trochus.*

3. *Turbinate;* conical with a convex base, as in *Turbo.*

4. *Turreted* or *elongated;* as in *Turritella.*

5. *Fusiform;* tapering to each end, as in *Fusus.*

6. *Cylindrical;* as in *Pupa.*

7. *Globular;* as in *Natica.*

8. *Convolute;* when the last whorl covers all the others and the aperture is consequently as long as the shell, as in *Cyprœa.*

9. *Auriform;* aperture very large and spire very short, as in *Haliotis.*

The surface of the shell is frequently ornamented with spines, or with ribs and striæ; these are said to be *longitudinal* or *spiral* when they run parallel to the sutures from the aperture to the apex; they are *transverse* when they run across the whorls from suture to suture. When rows of spines or processes extend across all the whorls from the apex to the base of the shell, as in *Murex,* we have what are termed *varices.* The surface of the shell in recent gasteropods is generally coloured, often variegated; in fossil examples the colour has nearly always disappeared, but a few specimens, from various formations, even as early as the Carboniferous, have been found showing the colour more or less perfectly preserved. The shell consists of an outer epidermal layer, and of a thick porcellanous layer; in some cases there is also an inner nacreous or pearly layer.

The Gasteropoda are divided into the following six orders:—(1) Polyplacophora, (2) Prosobranchia, (3) Opisthobranchia, (4) Heteropoda, (5) Pulmonata, (6) Pteropoda.

ORDER I. POLYPLACOPHORA.

The body is bilaterally symmetrical, and the shell is rmed of eight calcareous plates. This includes the enus *Chiton* and allied forms. The Order is only poorly presented in the fossil state; the earliest representatives curring in the Ordovician rocks.

ORDER II. PROSOBRANCHIA.

The gills and auricles are in front of the ventricle of e heart; in some cases there is only one gill and one ricle, in others there are two of each. There is nearly ways a shell. The sexes are separate.

Patella. Shell conical, oval or sub-circular; apex b-central or excentral, nearer the anterior border, often rved forwards; surface with radiating ribs or striæ, rely smooth. Margin simple or spinose. Muscular im- ession horse-shoe-shaped, open in front. Jurassic to esent day. Ex. *P. vulgata*, Pliocene to present day; *P. gosa*, Great Oolite.

Emarginula. Shell conical, surface ornamented with trellis-work of longitudinal and transverse ribs, apex rved posteriorly. Anterior border with a well-marked t. Muscular impression horse-shoe-shaped. Jurassic erhaps Carboniferous) to present day. Ex. *E. fissura*, ralline Crag to present day.

Fissurella. Shell similar to *Emarginula*, but more less depressed; apex perforated and nearer the anterior n the posterior border; no marginal slit. Muscular pression as in *Patella*. Jurassic (perhaps Carboniferous) present day. Ex. *F. crassa*, Recent; *F. græca*, Coralline g to present day.

Bellerophon (fig. 73). Shell globular, usually wit an umbilicus on each side; whorls few, symmetrically coiled in one plane. Aperture sub-circular or oval, with a deep median sinus, which is replaced by a band or keel dividing the shell into two similar parts; columellar edge often with callus. Upper Cambrian to Permian. Ex. *B. tenuifascia,* Carboniferous Limestone.

Fig. 73. *Bellerophon,* fro the Carboniferous Lim stone, showing the nus in the aperture. ×

Pleurotomaria. Shell trochiform, conical, turbinat or discoidal; interior nacreous. Umbilicus present absent. Aperture sub-quadrate or oval, outer lip shar with a slit which, as the shell grows, becomes filled u leaving a band on the whorls, toward which the lines growth are directed obliquely backwards. Operculu horny. Upper Cambrian to present day. Ex. *P. anglic* Lias; *P. ornata,* Inferior Oolite.

Murchisonia. Shell turreted, with many, more less angular whorls, provided with a band as in *Pleurot maria.* Aperture oblong, with a slit, and a very sho anterior canal. Ordovician to Permian. Ex. *M. verneu liana,* Carboniferous Limestone.

Euomphalus. Shell depressed, discoidal, with wide and large umbilicus; whorls convex with a ridge the upper surface. Aperture polygonal; outer lip with slit on its upper surface. Silurian to Trias. Ex. *pentangulatus,* Carboniferous Limestone.

Turbo. Shell solid, turbinate or conical, who convex, interior nacreous. Aperture large, circular, enti

slightly produced anteriorly; outer lip sharp. Columella curved, flattened. Imperforate or with a small umbilicus. Operculum thick, calcareous, exterior convex, interior flat and spiral, nucleus central or sub-central. Jurassic (perhaps also Palæozoic) to present day. Ex. *T. marmoratus*, Recent; *T. rugosus*, Pliocene to present day. There are numerous sub-genera.

Phasianella. Shell elongated, oval or oblong, smooth, polished, without an umbilicus, interior not nacreous. Aperture oval, entire, rounded anteriorly, angular posteriorly; outer lip thin, simple, sharp. Columella smooth, flattened. Operculum calcareous, with an excentric nucleus. Upper Cretaceous (or earlier) to present day. Ex. *P. australis*, Recent; *P. gosauica*, Upper Cretaceous.

Cirrus. Shell sinistral, conical or sometimes nearly discoidal, with a very large umbilicus. Spire acute. Whorls irregular, ornamented with nodular ribs; last whorl large. Aperture rounded, entire. Trias to Inferior Oolite. Ex. *C. nodosus*, Inferior Oolite.

Trochus. Shell conical, whorls numerous and flat or slightly convex, spire sharp, the last whorl angular; base flat or nearly so. Aperture entire, oblique, rhomboidal, outer lip sharp. Columella twisted, with a prominent interior tooth-like protuberance or a fold. Operculum horny, multispiral, nucleus central. Trias to present day. Ex. *T. niloticus*, Recent. There are numerous sub-genera.

Nerita. Shell thick, solid, ovoid or semi-globose, without an umbilicus. Spire very short. Surface smooth or with spiral ribs. Aperture semicircular, entire; outer

lip thick, the interior generally denticulate; inner li flattened, with callus, and a straight denticulate borde Operculum calcareous, nucleus excentral. Cretaceous t present day. Ex. *N. ustulata*, Recent; *N. globosa*, Londo Clay and Bracklesham Beds.

Solarium. Shell conical, depressed, angular at th periphery. Aperture entire, sub-quadrate; lip shar Umbilicus wide and deep, limited by a sharp edge whic is generally crenulated. Operculum horny, spiral. Jurass to present day. Ex. *S. perspectivum*, Recent; *S. canalicu latum*, Barton and Bracklesham Beds.

Littorina. Shell thick, not nacreous internally, tu binate, few-whorled, without umbilicus. Aperture rounde angular behind, outer lip sharp. Columella flattene Operculum horny, paucispiral. Lias to present day. E *L. littorea*, Red Crag to present day.

Calyptræa. Shell conical, limpet-shaped, spiral, ape central; interior with a half-cup-shaped process under th apex and attached posteriorly. Cretaceous to presen day. Ex. *C. chinensis*, Coralline Crag to present day.

Natica. Shell oval, globular, generally smooth, spi short, last whorl very large. Aperture semilunar or ova entire; outer lip sharp, inner lip with callus, not crenulat Umbilicus present, often filled with callus. Operculu of same size as aperture, horny or calcareous, paucispira nucleus excentric. Trias to present day. Ex. *N. canren* Recent; *N. millepunctata*, Coralline Crag to present da There are numerous sub-genera.

Viviparus (= *Paludina*). Shell thin, turbinate, wit an epidermis; whorls convex, smooth or with faint rib Aperture entire, oval, slightly angular behind. Ope

ulum horny with concentric striæ, and excentral nucleus. Lower Cretaceous to present day. Lives in fresh water. Ex. *V. lentus*, Bembridge Beds, etc.

Scala (= *Scalaria*). Shell more or less umbilicate, urreted, spire elongate; whorls numerous, convex, sometimes separated, ornamented with transverse ribs or sometimes with lamellæ, frequently with spiral ribs also. Aperture circular, entire, margin thickened. Operculum orny, paucispiral. Trias to present day. Ex. *S. scalaris*, Recent; *S. grœnlandica*, Red Crag to present day.

Turritella. Shell without umbilicus, turreted, many-horled, whorls flat or slightly convex, ornamented with piral ribs and with striæ of growth; spire very long. Aperture oval or sub-quadrate, entire, outer lip thin. Operculum horny. Trias to present day. Ex. *T. terebra*, Miocene to present day; *T. imbricataria*, Barton and Bracklesham Beds.

Pseudomelania. Shell many-whorled, elongate, turriculate, without umbilicus, spire long. Aperture oval, entire, rounded in front, narrowed and angular behind; outer lip sharp. Columella smooth. Trias to Eocene. Ex. *P. heddingtonensis*, Corallian.

Melania. Shell elongate, with an epidermis, turreted, many-whorled, without umbilicus, apex sharp but usually corroded. Surface smooth, ribbed, or spiny. Aperture entire, narrow behind, rounded in front; outer lip sharp, slightly sinuous. Columella smooth. Operculum horny, oval, sub-spiral. Wealden to present day. Lives in fresh water. Ex. *M. amarula*, Recent; *M. acuta* (= *muricata*), Bembridge Beds, etc.

Nerinea (fig. 74). Shell elongate, with or without an umbilicus, whorls numerous. Aperture sub-quadrangular, oval or elongate, with a short anterior canal and a posterior slit near the suture, which becomes filled leaving a continuous band. Columella and also the interior of the whorls furnished with folds which are continuous to the apex. Inferior Oolite to Upper Cretaceous. Ex. *N. cingenda,* Inferior Oolite.

Fig. 74. *Nerinæa trachea* partly ground down to show the form of the interior. Great Oolite. (From Woodward.) × ½

Cerithium. Shell without an umbilicus, turreted, without epidermis. Whorls numerous, narrow, the last whorl always much shorter than the spire. Aperture oblong or semi-oval, with a short posterior canal and a well-marked recurved anterior canal; outer lip more or less thickened. Columella concave. Operculum horny, oval, paucispiral. Jurassic to present day. Ex. *C. adansoni,* Recent; *C. mutabile,* Barton and Brackleshaw Beds. There are several sub-genera[1].

Aporrhais (= *Chenopus*). Shell fusiform, without an umbilicus, whorls numerous, spire elongate. Aperture produced into a straight or curved anterior canal. Outer lip thick with an anterior sinuosity; lobed or digitate

[1] *Cerithium* is also used in a more restricted sense by some authors to include only forms in which the columella is thick and provided with a tooth-like tubercle, the outer lip is expanded in front, and the whorls are provided with varices.

ne of the processes being applied to the spire. Operulum small. Jurassic to present day. Ex. *A. pes-pelicani*, Coralline Crag to present day.

Strombus. Shell ovoid, ventricose, tuberculate or piny, without umbilicus. Spire with numerous whorls, he last very large. Aperture long, narrow, with a notch r a short canal anteriorly; often canaliculate posteriorly; uter lip expanded, thick, often lobed, with a deep notch ear the anterior margin. Operculum small, horny, clawhaped, with serrated edge. Cretaceous to present day. x. *S. pugilis*, Recent.

Rostellaria. Shell fusiform, spire elongated, comosed of many whorls, which are smooth or faintly ribbed. perture oblong, with a long straight or slightly curved nterior canal, and a posterior canal applied to the spire; uter lip expanded, thick. Operculum small, oval or clawhaped, edge not serrated. Eocene to present day. Ex. . *curta*, Recent; *R. lucida*, London Clay, etc.

Cypræa. Shell ovoid or elongate, convex, convolute, rface covered with shining enamel. Spire concealed. perture oblong and narrow, with a short canal at each d; outer lip, inflected and crenulated; inner lip crenuted. In the young form the outer lip is thin and the ire prominent. Cretaceous to present day. Ex. *C. auritiana*, Recent; *C. oviformis*, London Clay.

Buccinum. Shell oval or elongate, without an umlicus. Spire long. Whorls ventricose, smooth or with ngitudinal folds. Aperture oval, large; outer lip simple; terior canal short, truncated, a little reflected. Columella a little sinuous. Operculum small. Eocene to

present day. Ex. *B. undatum*, Coralline Crag to prese day.

Nassa. Shell ovate, without umbilicus, general ornamented. Aperture oval, with a short reflected anteri canal. Inner lip with callus, reflected on to the last who with a tooth-like projection near the anterior canal; out lip thick, crenulate internally. Columella truncated, pr vided with an oblique fold at its base. Upper Cretaceo to present day. Ex. *N. mutabilis*, Pliocene and living.

Purpura. Shell tuberculate, striated or lamellar, n varicose. Spire rather short, last whorl large. Apertu oval, large, with an oblique groove in front. Columel flattened, with callus. Operculum lamellar, nucleus e ternal. Pliocene to present day. Ex. *P. persica*, Recen *P. lapillus*, Red Crag to present day.

Murex. Shell oval or elongate, solid, spire promine and sharp, whorls convex, carrying three or more long tudinal varices, which may be spiny, foliaceous, or tube cular. Aperture rounded, anterior canal more or less lon narrow and tubular, often closed; no posterior cana outer lip thick. Operculum oval, nucleus sub-apic Upper Cretaceous to present day. Ex. *M. brandar* Recent; *M. frondosus*, Barton Beds.

Fusus. Shell without umbilicus, narrow, fusifor elongate; spire sharp and many-whorled. Aperture ova outer lip simple, thin. A long, straight, narrow anteri canal, not closed. Columella smooth, without fol Operculum oval. Cretaceous to present day. Ex. *colus*, Recent; *F. porrectus*, Barton Beds, etc.

Mitra. Shell fusiform, thick. Spire elevated, summ

ute. Aperture narrow, elongate, notched in front. olumella with oblique folds, of which the posterior are ie stronger; outer lip not reflected, thickened but not rooved internally. No operculum. Eocene to present ay. Ex. *M. episcopalis,* Recent; *M. labratula,* Brackle-am Beds.

Voluta. Shell ovate or fusiform, solid, thick, summit spire mammilated. Last whorl very large, aperture ongate, oval; canal very short, recurved; outer lip mple, often thick, rarely reflected. Columella with ob-que folds in front, of which the anterior are the stronger. o operculum. Upper Cretaceous to present day. Ex. *muricina,* London Clay and Bracklesham Beds.

Pleurotoma. Shell turreted, fusiform, spire long and arp. Aperture oval; outer lip curved, with a deep slit ar the suture; inner lip smooth. Canal long, straight, rrow. Operculum horny, ovate, acute, nucleus apical. pper Cretaceous to present day. Ex. *P. babylonia,* ecent; *P. dentata,* Bracklesham Beds.

Conus. Shell inversely conical, generally smooth. ire short, many-whorled. Aperture narrow, straight, th parallel or sub-parallel borders; outer lip thin, nple, no folds nor teeth, notched at the suture. Colu-lla straight, smooth. Operculum horny, much smaller n the aperture. Upper Cretaceous to present day. *C. marmoreus,* Recent; *C. deperditus,* Bracklesham ds. There are numerous sub-genera.

ORDER III. HETEROPODA.

The forms included in this order live in the open n at or near the surface. The foot is modified so as

to form a vertical fin; a shell is absent in some but whe present is always thin. Only a very few forms occur foss

ORDER IV. OPISTHOBRANCHIA.

The gills and auricle are placed behind the ventricl There is only one auricle. A shell is absent in son forms. All are hermaphrodite and all marine.

Avellana. Shell globular, ornamented with spir striæ or grooves, spire very short. Aperture narro curved, entire; outer lip much thickened, reflected e ternally, dentate internally. Inner lip thickened, wi two or three prominent folds. Cretaceous. Ex. *A. i crassata*, Blackdown Greensand.

Bulla. Shell solid, smooth, sub-globular or ovoi convolute. Spire concave. Aperture as long as the la whorl, rounded at both ends, widest in front; outer l sharp. Inner lip with callus. Upper Cretaceous to prese day. Ex. *B. ampulla*, Recent; *B. globulus*, London Cl and Bracklesham Beds.

ORDER V. PTEROPODA.

The Pteropods are all pelagic animals, and are alli to the Opisthobranchia. The head is not well mark and the foot is represented by two lateral wing-like fi A shell may or may not be present.

The three genera described below are usually placed the Pteropoda, but their systematic position is uncerta Holm considers that *Hyolithes* and *Conularia* are n related to each other, and states that their resemblance existing Pteropods is very slight.

Hyolithes (= *Theca*) (fig. 75). Shell straight, rarely rved, pyramidal, triangular in ction, smooth or striated; posrior part sometimes crossed walls. Aperture sometimes lique; provided with an operlum having the form of a half ne. Cambrian to Permian. x. *H. elegans,* Ordovician.

Fig. 75. *Hyolithes* from the Cambrian, showing the operculum. × ⅔.

Conularia. Shell thin, nerally straight, pyramidal; ction quadrangular, each lateral face with a median ngitudinal groove; posterior part of shell sometimes ovided with concave partitions. Surface ornamented th numerous transverse, parallel, angulated ridges. perture partly closed by triangular or lobed processes. dovician to Trias. Ex. *C. quadrisulcata,* Carboniferous.

Tentaculites. Shell thick, solid, in the form of a eatly elongated cone, straight or slightly curved; section cular, posterior extremity sharp or with a vesicular largement. Surface provided with prominent, transrse, parallel rings, and with transverse and longitudinal iæ. Ordovician to Devonian. Ex. *T. anglicus,* Bala ds.

ORDER VI. PULMONATA.

Gills are absent in the Pulmonata; respiration takes ce by means of a pulmonary chamber. A shell may absent, but when present is holostomatous. An operum is never found. All the genera are hermaphrodite, nearly all live on land or in fresh water.

Limnæa. Shell spiral, thin, horny; last whorl ve large, spire sharp. Aperture large, oval, rounded in fro Columella more or less twisted. Peristome sharp, enti Purbeck Beds to present day. Lives in fresh water. *L. stagnalis*, Pliocene to present day; *L. longiscata*, Head Beds, etc.

Planorbis. Shell discoidal, horny, whorls numero Aperture oblique; peristome simple, sharp. Jurassic present day. Freshwater. Ex. *P. corneus*, Red Crag present day; *P. euomphalus*, Headon Beds, etc.

Helix. Shell variable—conical, discoidal, or globul with or without an umbilicus; aperture oblique. Pe stome simple or reflected. Eocene to present day. Li on land. Ex. *H. nemoralis*, Pleistocene and living. Th are numerous sub-genera.

Distribution of the Gasteropoda.

Some of the Gasteropoda live on land, others in fr water, but the majority are marine; they are found in seas of all parts of the world, but are especially abund in warm regions and in comparatively shallow water. few forms can exist both on land and in water, *Ampullaria*, which commonly lives in lakes and riv and is also found on land. Some marine genera, s as *Littorina*, *Cerithium*, and *Purpura*, are able to liv fresh as well as in salt water; on the other hand s freshwater forms are at times found living in the *e.g. Limnæa*, *Neritina*, *Bithynia*, and *Planorbis*; thi especially the case in places where the water is less than the main mass of the ocean, as for instance in Baltic, where we find the genera just mentioned li

ide by side with *Littorina* and with the marine lamelli-ranchs *Cardium*, *Tellina*, and *Mya*. Of the six orders of he Gasteropoda, four are entirely marine, viz. the Poly-lacophora, Heteropoda, Opisthobranchia, and Pteropoda; he Prosobranchia are mainly marine. Nearly all the 'ulmonata are found on land or in fresh water.

In connection with the Gasteropoda a few words may e said with regard to the distribution of the marine Iollusca generally. Some forms live in mid-ocean at r near the surface; these include the Pteropods, the Ieteropods and a few other Gasteropods, as well as many 'ephalopods. Others live on the sea-bottom and are ound at almost all depths, but are much more abundant n shallow than in deep water. The deep-sea species have wide geographical range, owing to the uniformity of the onditions under which they live. The Mollusca which ccur in moderate depths have a smaller range and are istributed in regions or provinces, limited mainly by onditions of climate. Each province is marked by the bundance of certain genera and by the presence of some pecies which do not extend into other provinces; but ney are not separated by any sharp line, and very few enera are confined to one province. In the European egion the chief provinces[1] are: the *Arctic*, which includes ne polar seas and extends as far south as the north of celand and the North Cape; the *Boreal*, extending from ne last down to near the southern end of Norway and ncluding the Shetland Islands; the *Celtic*, including the oasts of Southern Sweden, the Baltic, Denmark, Northern rance and the British Isles; and the *Lusitanian*, com-rising the coasts of the Bay of Biscay, Portugal, the

[1] For a map of the provinces see Woodward's *Manual of the Mollusca.*

Mediterranean, and North-west Africa. In each provin the character of the molluscan fauna also varies with t nature of the sea-bottom, some genera (*e. g. Mya, Lutrar Scrobicularia*) being found especially on muddy botton others (*e. g. Natica, Turritella, Cypræa, Cardium*) on sand and yet others (*e. g. Buccinum, Littorina, Patella, Arca*) rocky.

The distribution of the Mollusca varies also with t depth of the sea, due to temperature (which as a wh decreases with the depth), to pressure, and to the gradu disappearance of light; in this respect five zones ha been traced:—

(1) *Littoral Zone*, extending between high and lo water marks; in Europe this is especially characterise by the abundance of the genera *Littorina, Troch Patella, Hydrobia, Haliotis, Fissurella, Solen, My Donax*, and *Cardium*.

(2) *Laminarian Zone*, ranging from low water dow to about 14 fathoms; in it algæ (*Laminaria*, etc.) a particularly luxuriant, and afford food for numerous phyt phagous mollusks. Some of the commonest genera m with are *Trochus, Nassa, Rissoa*, and *Ostrea*. Nudibranc are also very numerous.

(3) *Zone of Nullipores or Corallines*, from 14 about 35 fathoms, where the calcareous algæ (Corallinace are very abundant. It is characterised by the abundan of *Pleurotoma, Fusus, Chrysodomus, Buccinum, Natic Eulima, Venus, Dosinia, Astarte, Nucula, Arca. Lim* and *Pecten*.

(4) *Zone of Brachiopods and deep-sea Corals*, fro 35 to about 230 fathoms; off Europe *Oculina* is t common coral; Brachiopods and Polyzoa are abundan

Some of the chief mollusks are *Turritella, Odostomia, Dentalium, Tellina, Neœra,* and *Yoldia.*

(5) *Abyssal Zone,* extending from the preceding down to the greatest depths at which life has been found. In this zone the shells are mostly thin, colourless, transparent, and of small size; it is especially characterised by numerous Scaphopods; other common forms are *Pleurotoma, Fusus, Actœon, Scaphander, Philine, Arca, Nucula, Limopsis, Leda, Lima,* and *Pecten.* The remains of Pteropods which have fallen from the surface of the ocean after death are also numerous.

In the fossil state gasteropods are less abundant than lamellibranchs, although they exceed them at the present day. The earliest forms occur in the Cambrian; they belong to the holostomatous Prosobranchia, and throughout the Palæozoic formations this is the predominant group; no genera belonging to the siphonostomatous section are with certainty known to occur until the Trias is reached, but they become abundant in the Oolites, still more so in the Cretaceous, and in the Tertiary they are the predominating forms. The other orders are not nearly so well represented as the Prosobranchia. The Polyplacophora range from the Ordovician to the present day, and, although never abundant, they are less rare in the Palæozoic, than in later formations. The Heteropoda are represented by a few forms only, the first occurring in the Miocene. The Opisthobranchia range from the Carboniferous to the present day; they are moderately well represented in the Jurassic and Cretaceous formations, and become more abundant in the Tertiary. The Pulmonata are first found in the Carboniferous, but they are rare until the Tertiary is reached. The Pteropoda have been recorded from the Lower Cambrian, but the

nature and affinities of some of the earlier forms (*Hy-lithes, Conularia, Tentaculites*) are somewhat doubtful; is possible that they may not be Pteropods; but repre-sentatives of the order (which have been referred t the genus *Styliola*) certainly occur in the Silurian an Devonian.

The most important genera found in the differen systems are:—

Cambrian. *Bellerophon, Hyolithes, Conularia.*

Ordovician. *Bellerophon, Holopæa, Cyclonema, Maclurea, Con laria, Tentaculites.*

Silurian. *Pleurotomaria, Murchisonia, Bellerophon, Euomphalu Omphalotrochus, Holopella, Platyceras.*

Devonian. *Pleurotomaria, Murchisonia, Bellerophon, Loxonem Euomphalus, Macrocheilus, Tentaculites.*

Carboniferous. *Pleurotomaria, Murchisonia, Bellerophon, Lox nema, Euomphalus, Naticopsis, Macrocheilus, Conularia.*

Permian. *Pleurotomaria, Murchisonia, Loxonema, Macrocheilu*

Trias. *Pleurotomaria, Trochus, Loxonema, Scala* (= *Scalaria Naticopsis, Natica, Turritella.*

Jurassic. *Pleurotomaria, Amberleya, Cirrus, Trochus, Natic Pseudomelania, Nerinea, Cerithium, Alaria, Purpuroidea.*

Cretaceous. *Pleurotomaria, Solarium, Turritella, Natica, Viv parus* (= *Paludina*), *Cerithium, Scala* (= *Scalaria*), *Aporrhais, Ave lana.*

Eocene. *Xenophora* (= *Phorus*), *Calyptræa, Natica, Melani Turritella, Cerithium, Rostellaria, Rimella, Aporrhais, Cypræa, Cassi Lampusia* (= *Triton*), *Fusus, Pisania, Pyrula, Murex, Typhi Voluta, Oliva, Pleurotoma, Conus.*

Oligocene. *Neritina, Natica, Viviparus* (= *Paludina*), *Melani Cerithium, Potamides, Murex, Ancilla* (= *Ancillaria*), *Pleurotom Limnæa, Planorbis, Rissoa, Helix, Bulimus.*

Pliocene. *Trochus, Scala, Turritella, Emarginula, Natica, Li torina, Cerithium, Buccinum, Chrysodomus, Nassa, Purpura, Fusus.*

CLASS III. SCAPHOPODA.

The Scaphopoda include only a few genera, which in some respects resemble the lamellibranchs. The body is elongated, and bilaterally symmetrical; the mantle is cylindrical and open at both ends; it secretes a straight or slightly curved tubular shell which is also open at both ends. The foot is greatly elongated and can be protruded through the larger aperture of the mantle and shell. The animal is attached to the posterior part of the shell by means of a muscle; an odontophore is present, but the head is not well marked, and eyes and heart are absent. The sexes are separate. All the scaphopods are marine, and they often live buried in sand or mud. The earliest forms occur in the Ordovician rocks.

Dentalium. Shell conical or sub-cylindrical, attenuated posteriorly, slightly curved. Anterior aperture simple, not constricted; posterior aperture smaller, without a fissure. Surface ornamented with longitudinal striæ or ribs. Cretaceous (perhaps earlier[1]) to present day. Ex. *D. elephantinum*, Recent; *D. decussatum*, Gault.

CLASS IV. CEPHALOPODA.

The Cephalopods are more highly organised than any of the other mollusks; well-known forms are the cuttle-fishes, belemnites, ammonites, and the nautilus. Existing forms are always bilaterally symmetrical; the head is well marked; it is separated from the body by a constriction, and is especially characterised by the fact that the fore-

[1] Forms closely allied to *Dentalium* occur in rocks as old as the Devonian.

foot extends round the mouth, and its margin is produced into processes or arms (fig. 76 *e*, *f*), which are provided either with sucking-discs or tentacles, and are used in prehension and locomotion. The mid-foot is in the form of a tube termed the *funnel* (*d*), which opens in front to the exterior, and behind into the mantle-cavity (*c*). The

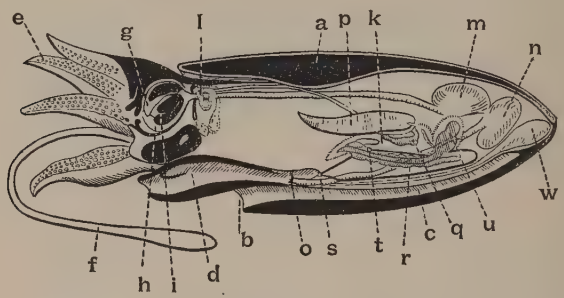


Fig. 76. Diagram of a vertical median antero-posterior section of *Sepia officinalis*. *a*, shell; *b*, mouth of mantle-cavity; *c*, mantle-cavity; *d*, funnel; *e*, lobes (arms) of the fore-foot; *f*, long arm of the fore-foot; *g*, the upper beak or jaw; *h*, the lower beak or jaw; *i*, odontophore; *k*, the viscero-pericardial sac; *l*, the nerve-collar; *m*, the crop; *n*, the gizzard; *o*, the anus; *p*, left gill; *q*, ventricle of the heart; *r*, renal glandular mass; *s*, left nephridial aperture; *t*, visceropericardial aperture; *u*, branchial heart; *w*, ink-sac. (After Lankester, *Zool. Art. Encyc. Brit.*)

funnel may be either a perfect tube or may be formed by the apposition of two troughs. The hind-foot is absent.[1] On the upper surface of the head there are two large eyes which, except in *Nautilus*, are almost as highly developed as in vertebrate animals. The mantle is formed by a single fold of the integument, which passes quite round the body of the animal; but dorsally the fold is very shallow so that the mantle-cavity exists mainly on the ventral surface

[1] These homologies of the foot are not accepted by all authors.

The gills (*p*) are placed in the mantle-cavity; in some forms there is one pair, in others two. A current of water flows in at the sides of the mantle-cavity, and is forced out through the funnel, by means of the contraction of the walls of the mantle-cavity. In the forms belonging to the Belemnoidea (Dibranchiata), a gland (known as the *ink-sac*, *w*) which secretes a black fluid (sepia) is present; the duct from this opens with the anus (*o*) into the mantle-cavity; the ink is ejected at times and passes out through the funnel, rendering the water cloudy, and by this means facilitating the escape of the animal from its enemies. Just within the mouth there are two jaws (*g*, *h*) which have the form of a parrot's beak, and are either horny or calcareous. An odontophore (*i*) is also present, out the arrangement of the teeth is less variable than in the gasteropods, and is of little value for systematic purposes. The heart consists of a median ventricle (*q*), and of lateral auricles, which are either two or four in number, according as there are two or four gills; it gives off in front an artery to the head, and one behind to the viscera. The nervous system is remarkable in that the ganglia are placed close together, forming a central mass (*l*); one part is placed above the œsophagus, and is connected by cords with the other part beneath it. This central nervous system is enclosed in a cartilaginous box and gives off nerves to the arms, viscera, etc. The sexes are always separate, and the genital ducts open into the mantle-cavity. In some forms there is no shell; but when present it may be external or internal (*a*); in the latter case it is usually placed in a sac in the mantle on the dorsal side. The Cephalopoda are divided into three Orders:—(1) Nautiloidea, (2) Ammonoidea, (3) Belemnoidea.

By many authors the Nautiloidea and Ammonoidea are grouped together as the *Tetrabranchiata*, and the Belemnoidea are known as the *Dibranchiata*. This classification is based primarily on the number of gills—the Tetrabranchiata possessing four, and the Dibranchiata two gills; since however the soft parts of the Ammonoids are quite unknown, and as the embryonic shell differs from that of the Nautiloids, it is probably better to separate the two groups.

ORDER I. NAUTILOIDEA.

In Palæozoic times the Nautiloid Cephalopods were very abundant, but at the present day the only representative of the group is *Nautilus*. *Nautilus* possesses two pairs of gills, two pairs of auricles, and two pairs of kidneys. An ink-sac is not present; the funnel is not a complete tube, but is formed of two parts. The arms are numerous and do not bear sucking-discs. The jaws are

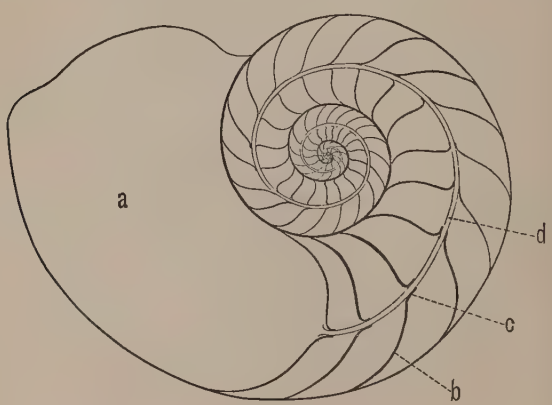


FIG. 77. Section of shell of *Nautilus pompilius*, Recent. *a*, body-chamber; *b*, septum; *c*, septal neck; *d*, siphuncle. × $\frac{1}{3}$.

calcareous. A shell is present in all forms and is always external; it consists of a tube, which tapers to a point at one end, and may be straight, arched, or spiral; in the spiral forms the whorls may be separate, or partly free, or in contact throughout; in some cases they are placed all in one plane, in others arranged in a helicoid spiral. The cavity of the shell, unlike that in the gasteropods, is not continuous throughout from the aperture to the apex, but is divided up into a number of chambers by means of partitions termed *septa* (fig. 77 *b*); the size of the chambers increases towards the aperture of the shell. The body of the animal is placed in the last chamber (*a*), to the walls of which it is attached by muscles. All the earlier chambers are filled with air only. Originally, of course, the animal lives in the earlier part of the shell, but as growth goes on, it successively withdraws towards the aperture, each time depositing behind it a septum and thus forming a new chamber. All the chambers are traversed by a tube known as the *siphuncle* (*d*), which is given off from the posterior part of the animal. The position of the siphuncle varies in different genera; in *Nautilus* it pierces the septa at or near their centres; in others it may be near the external margin, or near the internal margin of the whorl. In the modern *Nautilus* the siphuncle is membranous, except that it is coated with calcareous granules; but in some fossil forms it was completely invested by a calcareous tube. The interior of the siphuncle is frequently partly filled up with a calcareous deposit. The septa are often prolonged in the form of funnels around the siphuncle, so as to more or less completely insheathe it. These funnels are termed *septal necks* (*c*); in nearly all the Nautiloidea they are directed backwards.

In the genus *Nautilus*, the outer convex portion of the whorl is the ventral side, and the inner the dorsal; but in some fossil forms the opposite was the case, the outer being dorsal, and the inner ventral. It will therefore be more convenient to speak of the external and internal margins, instead of the dorsal and ventral. The margin of the aperture is in some cases even all round; in others, processes may be given off from the external margin or from the sides. In a few forms the aperture is constricted. The line where the edge of the septum unites with the tubular part of the shell is known as the *suture*; obviously this will only be seen when the shell is removed; but fossil forms frequently occur as casts and in these the sutures are admirably shown. One of the chief characters of the shell in the Nautiloidea is the simple form of the sutures; usually they are either straight or only slightly undulating.

The shell which covered the embryo in the Cephalopoda is known as the *protoconch*[1]; in the Nautiloidea this is seldom preserved, probably on account of its delicate nature. If the shell of a *Nautilus* be sliced in two, there will be seen at the centre a space which was probably occupied by the protoconch. At the apex of the first chamber will be found an opening which is usually slit-like and surrounded by either a rim or a depression; this opening probably served to connect the protoconch with the first chamber. The siphuncle commences in the first chamber as a closed tube.

Orthoceras. Shell straight or occasionally slightly curved, conical; transverse section usually circular. Septa simple, concave; body-chamber large; aperture not contracted or produced into lobes. Siphuncle usually slender, cylindrical, and central, but sometimes sub-central or ex-

central. Ornamentation variable. Tremadoc Beds to Trias. Ex. *O. annulatum*, Wenlock Limestone.

Actinoceras (fig. 78). Similar to the preceding, but the siphuncle is large and is inflated between the septa so that each segment is spheroidal, and contains in the interior a large amount of calcareous deposit. In the centre of the siphuncle is a small tube known as the *endosiphon* (*d*), from which radiating tubes (*c*) are given off between the septa and pass to the siphuncle. The 'endosiphon' probably represents the siphuncle of other forms. Ordovician to Carboniferous Limestone; in England chiefly Carboniferous. Ex. *A. giganteum*, Carboniferous Limestone.

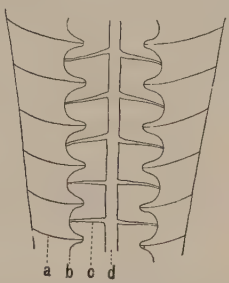


FIG. 78. Diagrammatic section of a portion of the shell of *Actinoceras*. *a*, septum; *b*, siphuncle; *c*, canals from endosiphon; *d*, endosiphon.

Gomphoceras (= *Phragmoceras*) (fig. 79). Shell fusiform, straight or curved; section circular, sometimes oval; body-chamber very long, aperture contracted, T-shaped. Siphuncle subcentral; in the nearly straight forms it is placed on the more convex side, in the curved forms it is nearer the concave side. Surface smooth or with transverse ribs or striæ. Silurian (perhaps also Ordo-

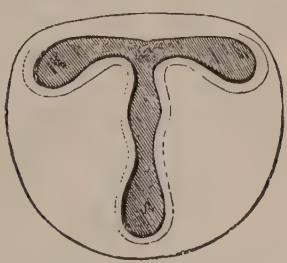


FIG. 79. Aperture of *Gomphoceras bohemicum* from the Silurian. (From Woodward.) Natural size.

vician, Devonian and Carboniferous). Ex. *G. ellipticum*, Lower Ludlow.

Ascoceras. Shell a little curved; the earlier part (which is rarely found) is like *Orthoceras*. The later formed part is sac-like and a little more convex on the ventral than on the dorsal side; the body-chamber occupies most of the ventral side; the septa join together and then bend round and divide again before reaching the dorsal side of the shell; the siphuncle of this part is very short. Ordovician and Silurian. Ex. *A. bohemicum*, Silurian.

Cyrtoceras. Like *Orthoceras* but always curved; never forming a complete volution; with the siphuncle usually sub-marginal. Cambrian to Carboniferous. Ex. *C. lineatum*, Devonian.

Nautilus (fig. 77). Shell more or less globose, spiral, whorls few, coiled in one plane, and more or less embracing. Umbilicus usually small or absent. Last chamber much larger than the preceding one, aperture simple, with an external sinus. Septa concave, sutures more or less undulating. Siphuncle central or sub-central, septal necks short and directed backwards. Surface of shell smooth or ornamented with striæ or ribs. Trias[1] to present day. Ex. *N. pompilius*, Recent; *N. pseudolineatus*, Inferior Oolite.

Discites. Shell spiral, compressed; whorls quadrangular, sometimes a little embracing, with the external margin flat or grooved. The last part of the shell is

[1] The species found in the Palæozoic formations which have usually been regarded as constituting sub-genera of *Nautilus* (*e.g. Discites*) are considered by recent writers to be distinct genera.

separated from the preceding whorl for a short distance. Carboniferous Limestone. Ex. *D. compressus.*

Aturia. Shell discoidal, whorls completely embracing; suture-line zig-zag, with a deep angular lobe on each side. Siphuncle on the internal margin; septal necks elongated, completely covering the siphuncle. Eocene and Miocene. Ex. *A. zic-zac*, London Clay.

ORDER II. AMMONOIDEA.

The Ammonoids are quite extinct and include the Ammonites, Goniatites, etc. The shell is generally coiled into a plane spiral, and as a rule the sutures are very complicated (fig. 80). The siphuncle is marginal and does not contain internal deposits. The septal necks in most forms are directed forwards.

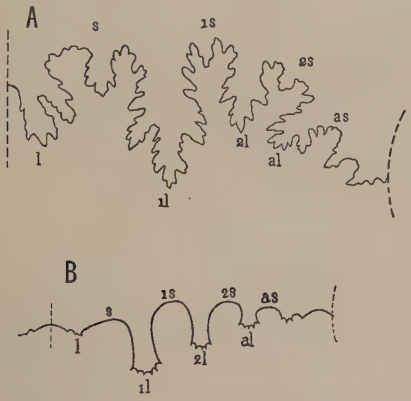


FIG. 80. *A*, suture of an Ammonite (*Parkinsonia parkinsoni*) from the Inferior Oolite. *B*, Suture of *Ceratites nodosus*, from the Muschelkalk. *l*, external lobe; 1 *l*, 2 *l*, superior and inferior lateral lobes; *al*, auxiliary lobes; *s*, external saddle; 1 *s*, 2 *s*, superior and inferior lateral saddles; *as*, auxiliary saddles. In each case the straight line on the left represents the position of the siphuncle, and the curved one on the right the line of contact with the next whorl.

The form of the sutures varies considerably in differen genera and is of great importance for systematic purposes usually they are folded many times, and in this way giv greater strength to the shell; the portions which are con vex towards the mouth of the shell are termed the *saddle* (fig. 80 *s*), whilst the intervening concave portions ar known as the *lobes* (*l*). In many forms the lobes an saddles exhibit secondary foldings, these may be sligh producing merely a denticulate structure, or they may b deep and provided with other foldings, giving a foliaceou appearance to the suture. The lobes and saddles ar similar on opposite sides of the shell; commonly there i first the external lobe (fig. 80 *l*) on the external margin then the superior and inferior lateral lobes (1 *l*, 2 *l*), an other lobes known as auxiliary lobes (*al*) may occur; o the internal margin is the internal lobe. The saddles ar arranged in a similar manner; there is the external saddl (*s*), the lateral saddles (1 *s*, 2 *s*), and auxiliary saddles (*as*

The protoconch of the Ammonoids is often preserved it is formed of calcareous material and is spherical o ovoid in shape. The siphuncle commences in the firs chamber of the shell.

In the last chamber of some Ammonites and a fe other forms, a pair of calcareous or horny plates, known as the *Aptychus* (fig. 81), are occasionally found; in shape they are triangular or nearly semicircular; the margins where the two plates are in contact are straight, the others curved. The aptychus probably served as an operculum.

Fig. 81. Aptychus of an Amm nite, from the Oxford Cla (From Woodward.)

When the shell is coiled in a plane spiral, its appearance depends mainly on whether the later whorls grow round the earlier, or are simply in contact with them; in some genera (fig. 84) the last whorl completely conceals all the previous ones, but in others (fig. 86) all the whorls are visible. In the latter case the umbilicus—which in these forms is present on both sides of the shell—is very large. The surface of the shell may be smooth or ornamented with striæ, ribs, tubercles, or spines. In some of the Ammonites (fig. 89) the external margin of the shell is provided with a ridge or *keel*, and in these forms the ribs of the two sides are not continuous. The keel may be smooth or toothed. The form of the ornamentation varies at different periods in the life of the individual, and by examining the early stages, which, in the case of the Ammonites, are preserved near the centre of the shell, it is possible to obtain indications of the ancestry of different forms. As in the case of the Brachiopoda (p. 122) it has been found that some forms, which in the adult state appear to be identical, have passed through different stages in development, such as to show that they have descended from different ancestors. Similarly in the Ammonites it may be seen that the form of the sutures changes when traced from the beginning of the first whorl to later parts of the shell. The earlier sutures are much simpler than the later and resemble those found on the adult whorls of certain Goniatites; hence it is considered that the Ammonites have descended from various groups of Goniatites.

Clymenia. Shell discoidal; whorls numerous, all visible, but each partly embracing the preceding one; the first chamber is long, generally occupying three-quarters

of the last whorl. Aperture with a ventral sinus. Suture with simple lobes. Siphuncle on the internal margin septal necks directed backwards. Surface usually orna mented with transverse striæ. Upper Devonian. Ex. *lævigata, C. undulata, C. speciosa.*

Anarcestes[1]. Shell almost discoidal. Sutures ver simple; the external lobe funnel-shaped and not divide by a saddle; lateral lobe very flat. Siphuncle[2] at th external margin; septal necks long. Body-chamber lon Devonian. Ex. *A. plebeius,* Lower Devonian.

Glyphioceras (fig. 82). Shell smooth or striate whorls rounded and generally large and embracing; un bilicus small or absent. Septal necks short. Extern lobe divided by a saddle; external saddle narrow; later lobe sharp and deep; lateral saddle broad, rounded, ar undivided. Carboniferous. Ex. *G. sphæricum, G. crenistri*

Fig. 82. *Glyphioceras sphericum,* from the Carboniferous Limesto The shell has been dissolved exposing the sutures. *A,* side vie *B,* view showing aperture with the siphuncle at the external (upp margin. (From Woodward) × ⅔.

[1] This and the two following, with several other genera, have usua been grouped together under the name *Goniatites*; but the differen exhibited by these forms are so great that they can no longer be regar as belonging to one genus.

[2] In all the following genera the siphuncle has this position.

Prolecanites. Shell smooth or striated, flattened, with a large umbilicus. Lobes and saddles numerous. External lobe not divided; lateral lobes sharp; lateral saddles narrow and rounded. Devonian and Carboniferous. Ex. *P. henslowi*, Carboniferous Limestone.

Ceratites (figs. 80 *b*, 83). Shell discoidal, ornamented with ribs or tubercles, external margin broad; umbilicus large; body-chamber short. Saddles rounded, lobes denticulate; external lobe broad and short. Trias, especially Muschelkalk. Ex. *C. nodosus*, Muschelkalk.

FIG. 83. *Ceratites nodosus*, from the Muschelkalk. The shell has been removed exposing the sutures. $\times \frac{2}{3}$.

Trachyceras[1]. Shell highly ornamented with ribs which bear tubercles or spines arranged in spiral rows; at the external margin is a groove; umbilicus generally small. Body-chamber short. Lobes and saddles denticulate. Trias. Ex. *T. aon.*

Oxynoticeras. Shell flattened; umbilicus small; external margin sharp, or keeled; surface smooth or striated. Sutures not deeply divided; external saddle large; auxiliary lobes present. Lias to Lower Cretaceous. Ex. *O. oxynotum*, Lower Lias.

[1] This and the following genera which are coiled in a plane spiral were formerly regarded as constituting a single genus—*Ammonites*. The genera now adopted are founded mainly on the form and ornamentation of the shell, the character of the sutures, and the length of the body-chamber.

Amaltheus. Shell flattened, provided with a sharp or toothed keel; umbilicus generally small; surface smooth striated or ribbed. Aperture with a long process at the external margin. Lobes and saddles deep and much divided, with several auxiliary lobes. Jurassic. Ex. *A. margaritatus*, Middle Lias.

Arcestes. Shell smooth or striated, nearly globular; umbilicus small or absent; aperture without lateral projections; body-chamber very long. Lobes and saddles numerous and foliaceous, gradually decreasing in size from the external to the internal margin; there are two lateral lobes and many auxiliary lobes. Trias. Ex. *A. intuslabiatus*, Upper Trias.

Fig. 84. *Phylloceras heterophyllum*, from the Lias. $\times \frac{1}{4}$.

Phylloceras (figs. 84, 85). Shell smooth or with fine striæ or gentle folds (never with tubercles); external margin rounded; umbilicus very small or absent. Saddles and lobes numerous; saddles divided, the extremities being rounded; auxiliary lobes numerous. Jurassic (perhaps also Cretaceous). Ex. *P. heterophyllum*, Upper Lias.

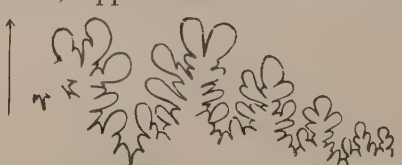


Fig. 85. Suture line of *Phylloceras heterophyllum*, from the Lias. The arrow indicates the position of the siphuncle and points towards the aperture of the shell. (From Woodward.) Natural size.

Lytoceras (fig. 86). Shell ornamented with ribs, and often with laminar projections (varices) placed at intervals. Whorls rounded, and only slightly or not at all embracing. Suture-line finely divided, consisting of an external lobe, two lateral lobes, and an internal lobe; of an external saddle and two lateral saddles. The lateral lobes and saddles nearly or quite symmetrically divided. Lias to Cretaceous. Ex. *L. fimbriatum*, Middle Lias.

Fig. 86. *Lytoceras fimbriatum*, from the Middle Lias. $\times \frac{1}{4}$.

Hamites. Shell bent upon itself three times, the parts not in contact; the last chamber long. Suture-line similar to *Lytoceras*, with the lateral lobes deeply divided. Surface smooth, or ornamented with ribs, tubercles, or spines. Lower Greensand to Chalk. Ex. *H. attenuatus*, Gault.

Macroscaphites (fig. 87). Similar to *Lytoceras*. Discoidal; whorls only slightly embracing, the last produced and then bent back in the form of a hook. Lower

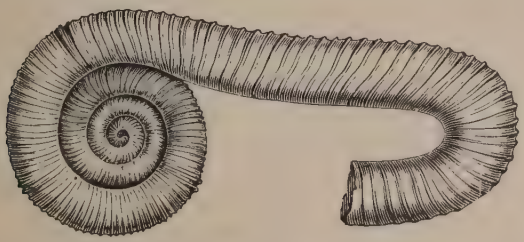


Fig. 87. *Macroscaphites ivani*, from the Lower Cretaceous. $\times \frac{1}{6}$.

Cretaceous. Ex. *M. ivani,* Lower Cretaceous; *M. giga.* Lower Greensand.

Turrilites. Shell spiral, turreted, usually sinistral, a the whorls in contact. Sutures similar to *Lytocera.* Surface ornamented with ribs or tubercles. Gault t Chalk. Ex. *T. costatus,* Chalk.

Baculites. Shell straight (except the first-forme part which is spiral), elongate-conical, elliptical in section last chamber large, aperture produced ventrally. Suture with the lobes symmetrically divided. Upper Cretaceou Ex. *B. vertebralis* (=*faujasi*), Chalk.

Psiloceras. Shell discoidal, umbilicus large; whorl increasing in size very slowly, external border rounde or with a very small keel; surface smooth or striate occasionally with ribs. Body-chamber large. Suture not much divided. Lower Lias. Ex. *P. planorbe.*

Arietites. Shell discoidal, umbilicus large, whorl numerous, only slightly embracing; with the externa border flattened and provided with a keel having a groov on each side of it. Surface with simple ribs, which ar straight or bent near the margin, and may bear tuber cles. Body-chamber occupying from one to one and a quarter whorls. Sutures much divided. Lower Lias. Ex. *A. bisulcatus.*

Ægoceras (fig. 88). Shell discoidal, with a large umbilicus; whorls rounded without a keel, ornamented with simple ribs which are continuous over the external

Fig. 88. *Ægoceras capricornu* from the Middle Lias. ×½.

margin. Lobes much divided; superior-lateral lobe larger than the others. Lias. Ex. *Æ. capricornum,* Lower and Middle Lias.

Harpoceras (fig. 89). Shell flattened, with a prominent even keel having a shallow furrow on each side; umbilicus small or of moderate size. Sides of shell with sickle-shaped undivided ribs. Aperture with projections. Sutures strongly divided; superior-lateral lobe deep. Lias. Ex. *H. serpentinum,* Middle and Upper Lias.

Fig. 89. *Harpoceras serpentinum,* from the Upper Lias. × $\frac{1}{6}$.

Dactylioceras. Whorls numerous, only a little embracing, without a keel; umbilicus large. Ribs numerous, at first straight, afterwards bifurcating; without tubercles. Body-chamber long. Sutures moderately divided; external lobe larger than the superior-lateral. Upper Lias and lower part of Inferior Oolite. Ex. *D. commune,* Upper Lias.

Stephanoceras. Whorls thicker than high, without a keel. Umbilicus large. Surface with straight ribs, which bifurcate on the sides of the whorls and often bear tubercles where they bifurcate. Body-chamber long. Aperture often with lobes. Sutures deeply divided; external lobe large; inferior-lateral lobe and auxiliary lobes small. Inferior Oolite to Oxford Clay. Ex. *S. humphriesianum,* Inferior Oolite.

Macrocephalites. Shell without a keel, whorls largely embracing, umbilicus small. Ribs numerous, dividing near

the umbilicus, continued over the external margin and without tubercles. Aperture without lobes. Sutures deeply divided, with auxiliary lobes. Great Oolite to Kellaways Rock. Ex. *M. macrocephalus*, Cornbrash.

Perisphinctes. Shell discoidal, external margin rounded; umbilicus generally large. Ribs straight, continuous, bifurcating near the external border. Constrictions are often present at intervals on the whorls. Sutures much divided; external and superior-lateral lobes large, inferior-lateral lobe small. Inferior Oolite to Cretaceous. Ex. *P. biplex*, Kimeridge Clay.

Peltoceras. Umbilicus large; whorls generally quadrilateral, the inner whorls with numerous continuous ribs most of which divide; the later whorls with two rows of tubercles on the sides, one near the outer, the other near the inner margin. Sutures moderately divided. Kellaways Rock and Oxford Clay. Ex. *P. athleta*, same range.

Parkinsonia (fig. 80 *A*). Shell discoidal, umbilicus large; ribs nearly straight, simple or bifurcating near the external border, but interrupted at the margin by a groove. Aperture with processes from the sides. Body-chamber short. Sutures deeply divided; external lobe a little larger than the superior-lateral. Inferior Oolite. Ex. *P. parkinsoni*.

Cosmoceras. Shell flattened; umbilicus large. Ribs numerous, bifurcating at the middle of the sides of the shell where there is generally a row of tubercles, and ending in a tubercle or spine at the external margin. Body-chamber very short. Aperture with long lateral lobes. Sutures much divided; the external lobe much shorter than the superior-lateral lobe; there are several

auxiliary lobes. Inferior Oolite to Lower Cretaceous. Ex. *C. jason,* Oxford Clay.

Hoplites. Shell flattened; umbilicus small. Ribs curved, bifurcating, and generally bearing near the umbilicus or at the middle of the sides a row of small tubercles; the external margin is flattened or deeply grooved. Sutures finely divided; many auxiliary lobes. Cretaceous. Ex. *H. splendens, H. interruptus,* Gault.

Acanthoceras. Whorls thick; umbilicus large; ribs simple or branching, with rows of tubercles at the sides and margin; external margin broad with a median row of tubercles. Saddles broad. Chalk. Ex. *A. rhotomagense.*

Crioceras. Shell coiled in a plane spiral; the whorls not in contact. Surface ornamented with ribs which in some cases bifurcate and often bear tubercles and spines. Sutures with four lobes. Upper Cretaceous. Ex. *C. ellipticum,* Chalk.

Ancyloceras. Like *Crioceras,* but the last whorl is produced in a straight line and then bent back in the form of a hook. Inferior Oolite to Lower Cretaceous. Ex. *A. spinigerum,* Gault.

Scaphites. Shell coiled in a plane spiral; the whorls in contact and embracing, except the last, which is detached from the spiral and then recurved in the form of a hook. Body-chamber long. Surface ornamented with bifurcating ribs which often bear tubercles. Sutures generally much divided, with several auxiliary lobes. Upper Cretaceous. Ex. *S. æqualis,* Lower Chalk.

Schlœnbachia. Shell with an umbilicus; external margin broad with a smooth keel; surface with strong

ribs, which are slightly curved forwards and often bea tubercles. External and superior-lateral saddles broad one auxiliary lobe. Cretaceous. Ex. *S. varians*, Lowe Chalk.

ORDER III. BELEMNOIDEA.

The Belemnoidea or Dibranchiata are represented a the present day by the various forms of cuttle-fishes; the are of much less importance geologically than the Nauti loids and Ammonoids, the only really common fossil genu being *Belemnites*. Some of the modern cuttle-fishes attai a length of forty feet or more.

The Belemnoidea possess one pair of gills only there are also one pair of auricles and one pair kidneys. The number of arms is limited to eight or ten and on the inner side—that facing the mouth—the are provided with rows of sucking-discs, which sometime possess horny hooks. The jaws are not calcified. An ink sac is always present and is occasionally found preserve fossil. The funnel is in the form of a complete tube. skeleton is absent in some forms; when present it internal, with the single exception of the genus *Argonaut* it may be either horny or calcareous. In some (*Sepia* etc it has the form of a flattened spoon-like body, known a the *pen*, which is composed mainly of laminated calcareou material; occasionally at the posterior end there is a sma chambered portion. The pen is placed on the dors surface of the animal in a sac formed by the mantle. I *Spirula* the shell is situated in the posterior part of th body, and consists of a tube coiled in a plane spiral ar divided up into chambers by means of septa, which a traversed by a siphuncle placed near the inner margi In *Belemnites* it consists of a solid portion (the "guard

and of a chambered part with a siphuncle. The shell in *Argonauta* is of quite a different nature to that found in other forms; it is spiral but not chambered, and is secreted mainly by the two dorsal arms; it is found only in the female, serving for the reception of the eggs.

The Belemnoidea are divided into two sub-orders:—(1) the Decapoda, (2) the Octopoda.

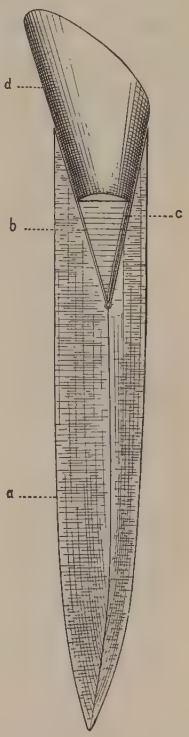


FIG. 90. Diagrammatic section of *Belemnites*. *a*, guard; *b*, phragmocone; *c*, siphuncle traversing the chambers of the phragmocone; *d*, pro-ostracum.

SUB-ORDER I. DECAPODA.

There are ten arms, eight of equal length and two longer than the others: the suckers are stalked and are provided with a horny ring. An internal shell is always present.

The genera *Spirula* and *Sepia* already mentioned belong to this sub-order; the former does not occur fossil and the latter only rarely. Allied to *Sepia* is the genus *Belosepia* found in the Eocene. The most important fossil form is *Belemnites*.

Belemnites (figs. 90, 91). The shell in this genus consists of two parts —the guard (fig. 90 *a*) and the phragmocone (*b*). The former is solid and is much more commonly preserved than the latter; it varies considerably in shape and size, being cylindrical,

fusiform, conical, etc. The posterior end is alway pointed; at the anterior end there is a conical cavity termed the alveolus. The length of the guard varie from one to fifteen inches.

When sliced transversely or longitudinally it is seen to be formed of a number of layers arranged concen trically around an axial line, which is not quite centra but is placed nearer the ventral surface; these layer are not of uniform thickness along the whole length of the guard, they become thicker towards the posterio end and are thinner towards the anterior. Each layer is formed of minute prisms of calcite, which are placed perpendicular to the axial line, thus producing a radiating fibrous appearance. The surface of the guard is sometimes smooth, or it may be granular, or furnished with ramifying vascular impressions; in some species there is a longitudinal groove on the ventral surface.

The phragmocone (*b*) is a conical tube which fits into the alveolus at the anterior end of the guard; it is divided up into chambers by septa which are concave in front; a siphuncle (*c*) traverses the chambers along the ventral margin. The wall of the

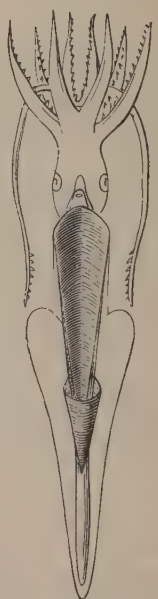


FIG. 91. D'Orbigny's restoratio of a Belemnite, showing th probable position of the guard the phragmocone, and the pro ostracum.

phragmocone (sometimes termed the *conotheca*) is very thin, and in well-preserved specimens the dorsal surface (or sometimes the lateral) is found to be produced in front into a large laminar expansion (*d*); this prolongation is known as the *pro-ostracum*, and corresponds to the "pen" of the cuttle-fish. The suckers on the tentacles were provided with horny hooks, which are occasionally preserved fossil; the ink-sac and mandibles have also been found in a few specimens. Lias to Upper Cretaceous. Ex. *B. acutus*, Lias; *B. oweni*, Oxford Clay, etc.; *B. hastatus*, Oxford Clay.

Belemnitella. This differs from the preceding genus in having a slit in the guard on the ventral side of the alveolus. There are well-marked vascular impressions on the ventral surface. Chalk. Ex. *B. mucronata*, Upper Chalk.

SUB-ORDER II. OCTOPODA.

There are eight arms only; the suckers are sessile and possess no horny ring. The shell is rudimentary or absent. This sub-order is very poorly represented in the fossil state; examples of it are *Octopus* and *Argonauta*, the latter has been found fossil in the Pliocene Beds.

Distribution of the Cephalopoda.

At the present day the Nautiloidea are represented by four species of *Nautilus* only; these occur in comparatively shallow water in the Indian Ocean, the Persian Gulf, the China Sea, and off New Guinea and Fiji. The group appears much earlier in the geological series than either the Ammonoidea or the Belemnoidea. Two genera (*Orthoceras* and *Cyrtoceras*) are found in the Upper Cambrian.

In the Ordovician the Nautiloidea are very much bette represented than in the Cambrian, the chief genera bein *Orthoceras, Cyrtoceras,* and *Endoceras.* The Order attaine its maximum development in the Silurian, where th number of species is very great; in the Devonian an Carboniferous there is a slight decline; in the Permia it is poorly represented. The only form which extend beyond the Palæozoic period is *Orthoceras,* which is foun in the Trias. *Nautilus* occurs first in the Trias and i especially abundant in the Cretaceous; in the Tertiary i is rare and is associated with the genus *Aturia.*

The distribution of the Ammonidea differs from that o the Nautiloidea in that the former are found mainly in th Mesozoic formations. *Clymenia* and various 'Goniatites occur in the Devonian and Carboniferous. Throughou the Mesozoic rocks the Ammonites are extremely abundant and attain their maximum development in the Lias; i the Cretaceous we get a remarkable development of mor or less completely uncoiled forms, *e.g. Hamites, Macrosca phites* (fig. 87), *Baculites, Crioceras, Ancyloceras,* an *Scaphites.* At the end of the Cretaceous the Ammonoide became extinct, except in California, where some Ammo nites have been found in the lower Tertiary beds.

The Belemnoidea or Dibranchiata are more numerou and more varied in existing seas than they were at an former period. Some forms are pelagic, others abyssa but they are most abundant in littoral regions and ar distributed in provinces similar to the other mollusks typical littoral genera are *Octopus, Sepia,* and *Loligo.* Th Belemnoidea are unknown in the Palæozoic formation the earliest examples appearing in the Trias. Throughou the Mesozoic, *Belemnites* is the chief form, and is especiall abundant in the clayey beds.

The genera which occur in the different formations are shown in the following Table:

Cambrian. *Orthoceras* and *Cyrtoceras* appear in the Upper Tremadoc Beds.

Ordovician. *Orthoceras*, *Cyrtoceras* and *Endoceras*.

Silurian. *Orthoceras*, *Cyrtoceras*, *Gomphoceras*, *Trochoceras* and *Ascoceras*.

Devonian. Nautiloidea:—*Orthoceras*, *Cyrtoceras* and *Gyroceras*. Ammonoidea:—*Clymenia*, *Anarcestes* and *Tornoceras*.

Carboniferous. Nautiloidea:—*Orthoceras*, *Cyrtoceras*, *Actinoceras*, *Gyroceras*, *Discites*, *Cœlonautilus* and *Temnocheilus*. Ammonoidea:—*Glyphioceras* and *Prolecanites*.

Permian. *Orthoceras*.

Trias. Nautiloidea:—*Nautilus* and *Orthoceras*. Ammonoidea:—*Pinacoceras*, *Ceratites*, *Trachyceras*, *Ptychites*, *Arcestes* and *Cladiscites*. Belemnoidea:—*Aulacoceras*.

Lias. Nautiloidea:—*Nautilus*. Ammonoidea:—*Oxynoticeras*, *Amaltheus*, *Phylloceras*, *Lytoceras*, *Psiloceras*, *Arietites*, *Ægoceras*, *Schlotheimia*, *Harpoceras*, *Cœloceras* and *Dactylioceras*. Belemnoidea:—*Belemnites* and *Geoteuthis*.

Oolites. Nautiloidea:—*Nautilus*. Ammonoidea:—*Haploceras*, *Stephanoceras*, *Macrocephalites*, *Perisphinctes*, *Peltoceras*, *Aspidoceras*, *Cosmoceras* and *Parkinsonia*. Belemnoidea:—*Belemnites* and *Acanthoteuthis*.

Cretaceous. Nautiloidea:—*Nautilus*. Ammonoidea:—*Macroscaphites*, *Hamites*, *Turrilites*, *Baculites*, *Pachydiscus*, *Hoplites*, *Acanthoceras*, *Crioceras*, *Scaphites* and *Schlœnbachia*. Belemnoidea:—*Belemnites* and *Belemnitella*.

Eocene. Nautiloidea:—*Nautilus* and *Aturia*. Belemnoidea:—*Belosepia*, *Beloptera* and *Spirulirostra*.

VI. ARTHROPODA.

Classes.		*Orders.*	*Sub-Orders.*
1. Crustacea.	1. Entomostraca.	1. Phyllopoda.	
		2. Trilobita.	
		3. Ostracoda.	
		4. Copepoda.	
		5. Cirripedia.	
	2. Malacostraca.	1. Leptostraca.	
		2. Thoracostraca.	1. Cumacea.
			2. Stomatopoda.
			3. Schizopoda.
			4. Decapoda.
		3. Arthrostraca.	1. Amphipoda.
			2. Isopoda.
2. Prototracheata.			
3. Myriapoda.			
4. Insecta		1. Aptera.	
		2. Orthoptera.	
		3. Neuroptera.	
		4. Lepidoptera.	
		5. Coleoptera.	
		6. Hemiptera.	
		7. Diptera.	
		8. Hymenoptera.	
5. Arachnida		1. Xiphosura.	
		2. Eurypterida.	
		3. Scorpionida.	
		4. Pseudoscorpionida.	
		5. Pedipalpi.	
		6. Araneida.	
		7. Phalangida.	
		8. Acarina.	
		9. Anthracomarti.	

In the Arthropods the body is bilaterally symmetrical and segmented, but all the segments are not alike; some (or all of them) bear a pair of jointed appendages. Some of the appendages near the mouth are modified to serve as organs of mastication and prehension. A chitinous exoskeleton is always present and is often strengthened by the deposition of carbonate or phosphate of lime. A heart is found in most forms; it is placed dorsally, and is provided with paired slits, termed ostia. The body-cavity contains blood. In some forms respiration takes place by means of the general surface of the body; others are provided with special organs—gills (or branchiæ), tracheæ, pulmonary sacs (or lung-books). The gills are generally processes borne by some of the appendages; the tracheæ are branching tubes filled with air and opening to the exterior; the pulmonary sacs or lung-books are infoldings of the integument. The nervous system consists of a supra-œsophageal ganglion, a ring round the œsophagus, and a ventral cord usually provided with ganglia, and placed beneath the intestine. Cilia are absent in all members of the group, with the exception of *Peripatus*. The sexes are separate in almost all forms.

The Arthropoda are divided into the following classes:—(1) Crustacea, (2) Prototracheata, (3) Myriapoda, (4) Insecta, (5) Arachnida. The members of the last four classes (with the exception of some of the Arachnida) breathe by means of tracheæ or pulmonary sacs, and are often grouped together as the *Tracheata*; the other forms, which are provided with gills, being known as the *Branchiata*. The Prototracheata include one genus only—*Peripatus*, which has not been found fossil.

CLASS I. CRUSTACEA.

The members of this class are mainly aquatic animals and are abundant as fossils; they breathe generally by means of gills, but in some cases by the general surface of the body. The chitinous exoskeleton is frequently hardened by a calcareous deposit,—hence the name Crustacea. Segmentation is usually well-marked, but is shown only by the appendages in the Ostracoda. Three regions may be distinguished in the body:—the head, the thorax, and the abdomen. There are five segments in the head, but these are indicated only by the appendages; the number in the thorax and abdomen is variable in one of the two great divisions, namely, the Entomostraca, but is constant in the other, the Malacostraca. In many forms some or all of the segments of the thorax (and sometimes also the anterior segments of the abdomen) fuse with those of the head to form a *cephalothorax*; this is covered dorsally by a large, unsegmented shield or carapace, termed the *cephalothoracic shield*. The head usually bears five pairs of appendages, viz. two pairs of antennæ, one of mandibles, and two of maxillæ. The thorax is also provided with appendages, and very often the abdomen too. The mandibles and maxillæ, and often also some of the anterior thoracic appendages, serve as jaws. The mouth is placed on the under surface of the head, and the anus is on the last segment of the abdomen. Eyes are generally present and are placed on the head; in some cases they are simple, in others compound, consisting of a number of lenses. The sexes are separate except in some cirripeds and isopods. In some cases development is direct, that is to say, the young individual has the same form as the adult; but generally this is not the case, the

young undergoing a metamorphosis before reaching the adult stage. The two chief larval forms are known as the *Nauplius* and the *Zoœa*. In the *Nauplius* form the body is unsegmented, and possesses three pairs of appendages representing the two pairs of antennæ and the mandibles. In the *Zoœa* stage some of the thoracic appendages are also present, and the abdomen is segmented but possesses no appendages.

The Crustacea are divided into two large groups, (A) the Entomostraca, (B) the Malacostraca.

A. ENTOMOSTRACA.

The forms included in this group are mostly of small size and of comparatively simple organisation. The number of segments in the body is variable, and also the number and form of the appendages; often the posterior part of the body is without appendages. In the development there is nearly always a *Nauplius* stage. There are five orders:—(1) Phyllopoda, (2) Trilobita, (3) Ostracoda, (4) Copepoda, (5) Cirripedia. The Copepods are not definitely known as fossils.

ORDER I. PHYLLOPODA.

The Phyllopoda include the water-fleas (*Daphnia*) and other forms. The body is segmented and often the greater part of it is covered by a carapace which may be shield-like or in the form of a bivalved shell. The number of segments in the abdomen and thorax varies very widely. On the head there are generally two pairs of antennæ, one of mandibles, and one or two of maxillæ. The thorax bears four or more pairs of swimming-feet, which are leaf-

like. The abdomen is frequently without appendages; it often ends in a caudal fork. Two large eyes are present and often also a small unpaired eye. The Phyllopods live mainly in fresh or brackish water. Only a very few genera are found fossil; the earliest occur in the Old Red Sandstone.

Estheria (fig. 92). Valves equal, thin, horny; ovate oblong or quadrilateral, united at the straight dorsal border; the apices of the valves placed anteriorly, or nearly central. Surface generally covered with concentric striæ. Old Red Sandstone to present day. Lives in fresh or rarely in brackish water. Ex. *E. minuta*, Trias, etc.

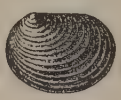


Fig. 92. *Estheria minuta* from the Trias. ×3.

ORDER II. TRILOBITA.

The Trilobites derive their name from the fact that the body is divided into three parts, by means of two furrows which extend from the anterior to the posterior extremities; in a few genera, however (*e.g. Homalonotus, Illænus*) this trilobation is only very feebly shown, or is almost absent. In a longitudinal direction, three regions can be distinguished in the body, the head (fig. 93 *A*), the thorax (*B*), and the pygidium (*C*); each of these regions is covered dorsally by a calcareous shell. That covering the head, and known as the head-shield or cephalic shield, is semicircular or triangular in shape and is not segmented; in it may be distinguished a median and two lateral portions; the former is the more convex and is termed the *glabella* (*a*), the latter are the *cheeks*. The glabella is marked off from the cheeks by means of a furrow on each

side, known as the *axal furrow* (*a'*). The form of the glabella varies in different genera; in some it extends

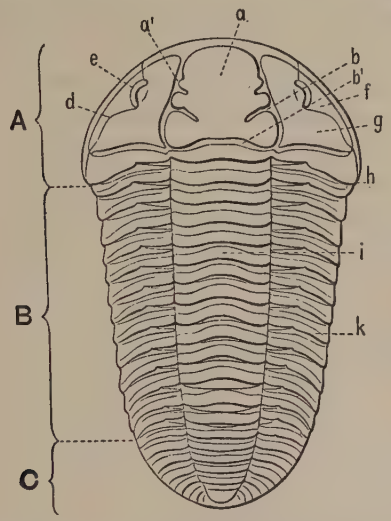


FIG. 93. *Calymene blumenbachi*, from the Wenlock Limestone. *A*, head, *B*, thorax, *C*, pygidium. *a*, glabella; *a'*, axal furrow; *b*, one of the glabella furrows; *b'*, neck furrow; *d*, facial suture; *e*, eye; *f*, free cheek; *g*, fixed cheek; *h*, genal angle; *i*, axis of thorax; *k*, pleura. Natural size.

quite to the anterior margin of the head-shield, in others only a part of the way (fig. 98); sometimes it is wider behind than in front; in other cases it is wider anteriorly, or it may be uniform throughout. Generally it is divided at the sides into lobes by means of transverse furrows (*b*), usually three on each side; in some cases the furrows from the two sides meet in the middle of the glabella. On the posterior part of the glabella there is another furrow, which extends quite across it; this is known as the neck-furrow (*b'*). These furrows are probably indications of the segments which

have become fused to form the head. The cheeks are each more or less triangular in shape and less convex than the glabella, they are frequently bordered by a flattened margin; in *Trinucleus* the margin is very broad and highly ornamented. The posterior angles of the cheeks, often spoken of as the genal angles (*h*), may be rounded (*e.g. Calymene*) but are often pointed or produced into spines (*e.g. Paradoxides*, fig. 99). Each cheek is divided into two portions by means of a suture (the *facial suture*, *d*). The inner part,—that between the facial suture and the glabella, is termed the *fixed cheek* (*g*) and is immovable; the outer part, known as the *free cheek* (*f*), is movable on the fixed cheek. The course of the facial suture varies in different forms; it may commence at the genal angle (*h*), or on the posterior border inside the genal angle (fig. 100), or on the external border just in front of the genal angle; it passes anteriorly and may be continuous with the suture of the other cheek in front of the glabella, or it may cut the anterior margin of the head-shield, in which case it is often united with the other suture on the inferior surface of the head (*e.g. Calymene*). When the sutures are continuous in front of the glabella, it is obvious that the cheeks will also be continuous. In some genera (*Agnostus*, *Trinucleus*) the facial suture is absent. The eyes (*e*) are placed on the upper surface of the head, one on each free cheek near the facial suture, and generally near the middle of the cheek; they are compound, each consisting of a number of lenses; in a few genera (*Agnostus*, *Ampyx*) eyes are absent; in *Æglina* (fig. 94) they are unusually large, occupying

Fig. 94. *Æglina binodosa*, Arenig Beds. Natural size.

the greater part of the free cheeks. The head-shield is continued on the under surface of the head forming a marginal rim (fig. 96 *a*); attached to this in the median line is a plate, usually oval in shape, situated just in front of the mouth and known as the *hypostome* or *labrum* (*b*; and fig. 95). Just behind the mouth is a small plate, the *metastoma* (fig. 97 *A*, *m*); up to the present time this has been observed only in the genus *Triarthrus*.

The thorax (fig. 93 *B*) is formed of a series of segments, which vary in number, from two to twenty-six; these are movable upon one another, in some cases sufficiently to enable the animal to roll itself up like a wood-louse. Each segment is divided into a central and two lateral parts by means of two furrows. The central part is more convex than the lateral, and forms the axis (*i*), the lateral parts being known as the pleuræ (*k*). The anterior part of the axis of each segment is not visible when the animal is unrolled, since it is overlapped by the preceding segment, for which it forms an articulating surface. The pleuræ in some genera possess a longitudinal ridge, in others a groove; a few forms have smooth pleuræ. Each pleura, at some distance from the axis, is curved downwards and usually also backwards; the point where this curvature occurs is known as the fulcrum; generally each pleura overlaps the anterior part of the succeeding one, and often the fulcrum is rounded so as to form an articulating facet. The terminations of the pleuræ are in some cases rounded (fig. 93), in others produced into spines (fig. 99).

Fig. 95. Hypostome of *Asaphus tyrannus*, from the Llandeilo Beds. Reduced.

The pygidium (fig. 93 *C*) is usually triangular or semicircular in shape, and is formed of a variable number of

segments, which differ from those of the thorax in bein fused together and immovable; the segmentation is shov by grooves only. The pygidium, like the thorax, possess a central part or axis, and lateral portions; the axis ma reach quite to the posterior extremity or only part of th way; in *Bronteus* it is very short. The margin of th

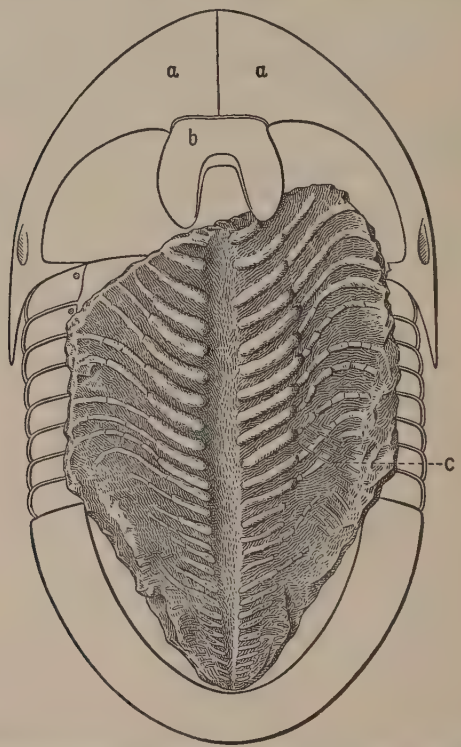


FIG. 96. Under surface of *Asaphus megistos*, from the Ordovician ro of Ohio, showing a pair of appendages attached to each segme The shaded part represents the actual specimen. *a*, infolded mar of the head-shield; *b*, hypostome; *c*, branchial filaments? (A Walcott.)

pygidium may be even or entire, or it may be provided with a posterior spine or with lateral spines.

For a long time the appendages of the trilobites were unknown. Only a very few specimens showing the ventral surface have been found; one of these is an example of *Asaphus megistos* (fig. 96) from the Ordovician Beds of Ohio. In this, each segment of the thorax and pygidium was found to bear a pair of jointed appendages. Walcott has obtained further information on this subject by cutting thin sections of rolled up specimens of *Calymene* and *Cheirurus*. By this method he ascertained that on the ventral surface of the body there was a thin membrane, strengthened by transverse arches to which the appendages of the thorax and pygidium were attached; each of these appendages consisted of six or seven joints, and at the base a spiral structure (probably a gill) was attached. The head also carried pairs of jointed appendages.

Specimens showing the ventral surface much more perfectly have recently been obtained from the Utica Slate near Rome (New York) and have been fully described by Beecher. The most important of these belong to the genus *Triarthrus* (fig. 97); they are not curled up, and exhibit very clearly the form of the limbs. Each segment of the body bears one pair of appendages. On the head there are five pairs; the *first* are the long antennæ which have a large basal joint and are attached to the head on each side of the hypostome (*h*). The antennæ represent the antennules (or anterior antennæ) of other Crustacea. The remaining four pairs of appendages of the head are biramous and all have nearly the same form but increase in size backwards; the *second* pair represent the antennæ, the *third* the mandibles, and the *fourth* and *fifth* pairs the maxillæ of other Crustacea. The maxillæ

consist of a large basal joint (the *coxopodite*) which bea the *endopodite* and the slender *exopodite*; the latt carries a bunch of hairs or *setæ*.

The anterior appendages of the thorax are long a

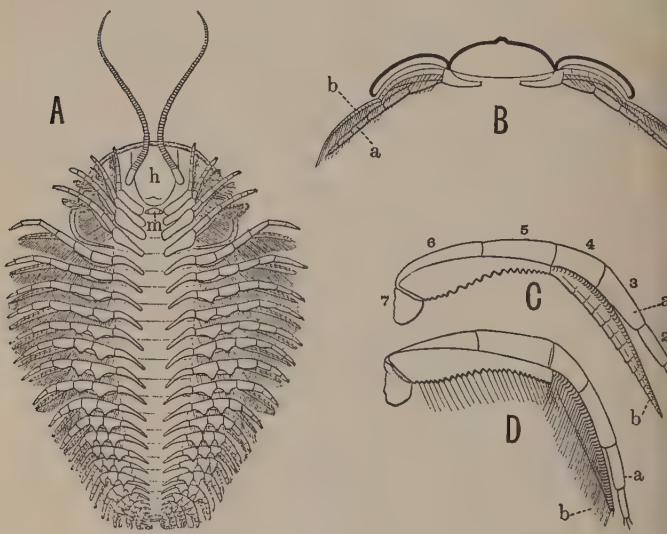


Fig. 97. *Triarthrus becki*, from the Utica Slate (Ordovician) near Ro New York. (After Beecher.)

A, view of the ventral surface showing appendages etc. *h*, hy stome; *m*, metastoma. $\times 1\frac{2}{3}$.

B, diagrammatic section through the second thoracic segme *a*, endopodite; *b*, exopodite.

C, *D*, dorsal view of the right legs of the second and third thora segments (setæ omitted from *C*). *a*, endopodite; *b*, exopodi $\times 12$.

consist of a coxopodite (fig. 97 *C*, *D*) which apparent bears the six-jointed endopodite (*a*) and the exopodite (*b*) the first joint of the latter is large, the others small a numerous. The exopodite bears setæ and probably serv

as a swimming organ, whereas the endopodite was adapted for crawling. The posterior thoracic limbs do not differ essentially from the anterior one just described, but they diminish in size posteriorly and were better adapted for swimming.

The appendages of the pygidium are leaf-like and resemble closely the limbs of Phyllopods, particularly *Apus*. The leaf-like character is due to the expansion of the first segments of the endopodite which bear setæ; the exopodite is slender. The anal opening is quite at the end of the pygidium.

The possession of antennæ, and the character of the other appendages, show that the Trilobites belong to the Crustacea; it is difficult to fix their position exactly, since they show affinities to more than one group. The great variability in the number of segments connects them with the Entomostraca; the leaf-like character of the appendages on the posterior part of the body shows that they are related to the Phyllopoda and especially to the genus *Apus*. On the other hand the anterior thoracic limbs resemble those of the Schizopods.

The Trilobites also show some affinities with the Xiphosura (p. 264). They agree with *Limulus* in the trilobation of the body and in the possession of a similar shield covering the anterior part of the body; with the Palæozoic Xiphosurans the resemblance is more marked, since some of these possess facial sutures and have the segments of the posterior part of the body free. The larval form of *Limulus* is similar to the adult stage of some trilobites, particularly *Trinucleus*; in the larva the caudal spine is absent and the segmentation of the body is better marked. The Trilobites differ from the Xiphosurans in the absence of ocelli, in the possession of a

hypostome, and particularly in the form and arrangeme of the appendages.

Agnostus. Body small, head-shield and pygidiu similar in form and size; eyes and facial suture absen glabella does not reach the anterior border of the hea Thorax formed of two segments, axis wide, pleuræ groove *Olenellus* Beds to Bala Beds. Ex. *A. pisiformis*, Lingu Flags.

Microdiscus. Similar to *Agnostus* but with fo segments in the thorax. *Olenellus* Beds to Lingula Flag Ex. *M. punctatus*, Lingula Flags.

Trinucleus. Head-shield large, with long gen spines, and a broad punctate border; glabella inflate pyriform, furrows absent or indistinct. Eyes general absent. No facial suture. Thorax formed of six se ments, pleuræ grooved, straight, but slightly curved ne their extremities. Pygidium short, triangular, marg entire. Arenig to Bala Beds. Ex. *T. concentricus*, Ba Beds.

Ampyx. Similar to *Trinucleus*, but with a triangul head-shield which is without a punctate border, wi a long straight spine given off from the front of the glabella; also with discontinuous facial sutures. Tremadoc to Wenlock Beds (only one species in the latter). Ex. *A. nudus*, Llandeilo Beds.

Fig. 98. *Olenus cataractes*, fr the Lingula Flags. Natu size.

Olenus[1] (fig. 98). Body oval; head-shield larger than

[1] The species included under this name differ considerably, a should probably be regarded as constituting several distinct genera.

the pygidium, with a narrow border, and with genal spines; glabella, separated from the anterior border by a flat space, usually a little contracted in front, furrows often extending quite across; facial sutures discontinuous in front; eyes well-developed, placed forward and united to the front of the glabella by a straight ridge. Thorax of from twelve to fifteen (typically fourteen) segments, pleuræ pointed. Pygidium small. Lingula Flags to Tremadoc Beds. Ex. *O. alatus, O. cataractes, O. scarabæoides, O. spinulosus,* Lingula Flags.

Paradoxides (fig. 99). Body large, elongated, narrowed posteriorly. Head-shield broad, semicircular, with a border, and long genal spines; glabella broad in front, with two to four furrows on each side. Facial sutures extend from the posterior to the anterior border. Eyes large and arched. Thorax long, formed of sixteen to twenty segments; pleuræ grooved and produced into long backwardly directed spines. Pygidium very small, axis of two to eight segments. Solva Beds to Lingula Flags. Ex. *P. davidis,* Menevian Beds; *P. bohemicus,* Cambrian.

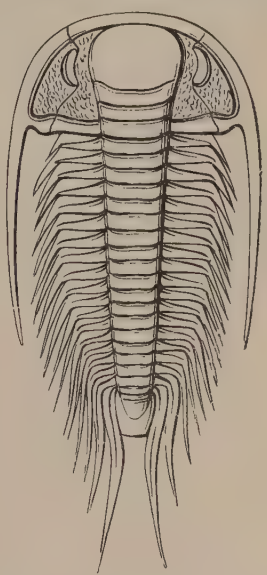


Fig. 99. *Paradoxides davidis,* from the Menevian Beds. Reduced.

Olenellus. Similar to *Paradoxides*; but the glabella is either of nearly the same width throughout, or narrows

slightly in front, the facial sutures are invisible, the ey
are large and join on to the glabella, there are from thirtee
to eighteen segments in the thorax. Some forms hav
spines on the axis of one or more segments of the thora
and pygidium. In some species there are no lateral lob
on the pygidium. Lower Cambrian. This genus is divide
into four sub-genera; one species of each is here men
tioned:—Ex. *Olenellus* (restricted) *thompsoni*, *O.* (*Mes
nacis*) *vermontana*, *O.* (*Holmia*) *callavei*, *O.* (*Olenelloide
armatus*.

Conocoryphe (= *Conocephalites*). Head-shield sem
circular, with or without genal spines; axal furrows dee
glabella narrow in front and with three or four back
wardly directed furrows; free cheeks small. Facial suture
not continuous in front and ending near the genal angle
Hypostome convex, formed of a central oval portion su
rounded by a narrow border. Thorax with fourteen
fifteen segments. Pygidium small, margin entire, ax
with from two to eight segments. *Olenellus* Beds
Tremadoc Beds. Ex. *C. lyelli*, Solva Beds; *C. sulzer*
Cambrian.

Angelina. Body oval. Head-shield with long gen
spines, glabella without furrows; eyes small, near th
middle of the cheeks. Thorax with fourteen or fiftee
segments, pleuræ facetted. Pygidium short, margin pr
vided with two teeth, axis formed of four or five segment
Tremadoc Beds. Ex. *A. sedgwicki*.

Calymene (fig. 93). Head shield semicircular, gen
angles rounded, occasionally pointed; glabella great
inflated, broadest behind, with three pairs of later
furrows, forming three globular lobes on each side. Ey
prominent. Facial sutures extending from the gen

angles to the anterior border, where they are connected by a marginal suture. Thorax formed of thirteen segments, axis prominent, pleuræ grooved and facetted. Pygidium with six to eleven segments, margin entire. Arenig to Upper Ludlow. Ex. *C. blumenbachi*, Wenlock Limestone etc.

Homalonotus. Body large, elongated, with indistinct trilobation. Head-shield broad, genal angles rounded, furrows on the glabella indistinct or absent. Eyes small. Facial suture passing from the genal angles to the front margin, but often continuous in front. Thorax with thirteen segments; axis wide, not well-marked. Pygidium rather small, triangular, axis with ten to fourteen segments. Arenig to Devonian. Ex. *H. delphinocephalus*, Wenlock Beds; *H. bisulcatus*, Ordovician.

Ogygia. Body large, nearly flat. Head-shield large, semicircular; glabella distinct, wider in front, with four lateral furrows. Eyes large. Facial suture starting from the posterior border, sometimes cutting the front margin, but generally continuous. Hypostome not notched. Thorax consisting of eight segments, axis narrow, distinct; pleuræ grooved. Pygidium large, semicircular, margin entire, axis of numerous segments. Tremadoc to Llandeilo Beds. Ex. *O. buchi*, Llandeilo Beds.

Asaphus (figs. 95, 100). Body oval, surface smooth or with striæ. Head-shield semicircular with a flattened border, genal angles rounded or spinose; glabella wide in front and usually without lateral furrows. Eyes large. Facial sutures sometimes continuous, sometimes cutting the anterior margin. Hypostome notched posteriorly. Thorax formed of eight segments, pleuræ obliquely grooved, with rounded extremities. Pygidium of about

the same size as the head, rounded, formed of numerou segments which are usually visible on the axis only; margin entire. Tremadoc to Bala Beds. Ex. *A. tyrannus*, Llandeilo Beds.

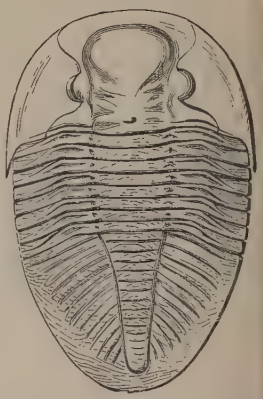


Fig. 100. *Asaphus tyranni* from the Llandeilo Beds. R duced.

Illænus. Body oval, convex. Head-shield large, semicircular; glabella indistinctly marked, without furrows externally, but within the test there are four pairs. Eyes remote from one another. Facial sutures commence on the posterior border, cut the anterior border in front of eye, and unite on the inferior surface. Thorax wi usually ten segments, axis usually not well-marke pleuræ not grooved or ridged. Pygidium large, sen circular, axis rudimentary, segments not visible external Arenig to Wenlock. Ex. *I. bowmanni*, Bala Beds.

Æglina (fig. 94). Head-shield large; glabella larg convex, projecting beyond the margin in front. Chee narrow; eyes very large. Facial sutures discontinuo nearly parallel to the axis of the body. Thorax with fi or six segments, pleuræ grooved. Pygidium rounded, a reduced. Arenig to Bala Beds. Ex. *Æ. binodosa*, Lla deilo Beds.

Bronteus. Head-shield large, semicircular, ge angles pointed. Glabella very wide in front, with th lateral furrows in some species, none in others. Fac sutures discontinuous in front, eyes sickle-shaped, plac

near the posterior border. Thorax with ten segments, axis narrow, pleuræ ridged. Pygidium very large, fan-shaped, axis short, lateral lobes large with radiating grooves. Bala Beds to Devonian. Ex. *B. flabellifer*, Devonian.

Phacops. Head-shield nearly semicircular, glabella prominent, broadest in front, with three or four furrows, which are sometimes indistinct; facial sutures commencing on the lateral borders of the cheeks in front of the genal angle, and continuous in front of the glabella. Eyes generally large, granulated, formed of large facets. Thorax with eleven segments, pleuræ grooved. Pygidium variable. Ordovician to Devonian.

The species of *Phacops* are grouped into a number of sub-genera, some of which (together with a typical species in each case) are here mentioned:—*Phacops* (restricted) *stokesi*, Silurian; *Trimerocephalus lævis*, Devonian; *Acaste downingiæ*, Silurian; *Chasmops conophthalmus*, Bala Beds; *Odontochile* (= *Dalmanites*) *caudatus*, Silurian.

Cheirurus. Head-shield semicircular, genal angles pointed; glabella convex, oblong or ovoid, with three pairs of furrows which are sometimes continuous across, the last pair uniting with the neck-furrow. Facial sutures continuous in front and ending on the external margins. Eyes prominent. Thorax with usually eleven segments, pleuræ grooved, and produced into spines. Pygidium with four segments, lateral lobes with backwardly-directed spines. Tremadoc to Devonian. Ex. *C. articulatus*, Devonian; *C. bimucronatus*, Bala to Ludlow Beds; *C. juvenis*, Bala Beds.

Encrinurus. Head-shield covered with tubercles;

glabella pyriform, its furrows indistinct or absent; eye small, placed on short peduncles. Facial sutures ne continuous, ending on the lateral margins. Thorax wit eleven segments, pleuræ ridged. Pygidium narrow, tr angular, with many segments in the axis, pleuræ ben backwards. Bala to Upper Ludlow. Ex. *E. punctatu* Wenlock Limestone.

Acidaspis (fig. 101). Head-shield broad, trilobatic not well-marked, genal angles spined; glabella with

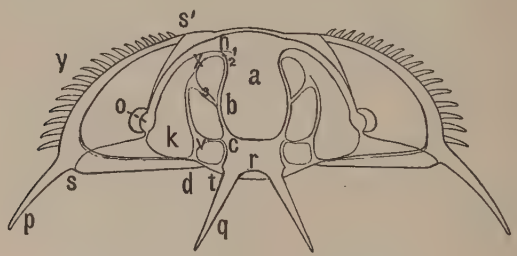


Fig. 101. *Acidaspis prevosti*, from the Silurian Rocks. Outline of t head-shield. (After Barrande.) 1, 2, 3, first, second, and thi glabella furrows (the first usually indistinct); *a*, central part of t glabella; *c—b—n*, inner furrow of glabella; *c—v*, neck-furro *d—v—x*, axal furrow; *k—x*, fixed cheek; *o*, eye; *o—n*, ridge e tending from eye to glabella; *p*, genal spines; *q*, spines from ne ring; *r*, neck ring; *s—s'*, facial suture; *y*, spines. Enlarged.

pair of longitudinal furrows parallel to the axal furrov and with two or three lateral furrows. Eyes connect with the glabella by a ridge. Facial sutures continuo in front and ending on the posterior margin, but som times absent. Thorax with nine or ten segments, pleu produced into long spines. Pygidium small, with lo spines. Llandeilo Beds to Devonian. Ex. *A. barrand A. brighti*, Wenlock Beds.

Phillipsia. Body oval; glabella with nearly parallel sides, with two or three short lateral furrows, the posterior one being directed backwards and united to the deep neck-furrow, thus cutting off a basal lobe. Eyes large, reniform. Facial sutures cut the posterior border obliquely and the anterior border in front of the eye. Thorax with nine segments, pleuræ grooved. Pygidium semicircular, formed of from twelve to eighteen segments, margin entire. Devonian to Permian. Ex. *P. derbiensis*, Carboniferous.

Griffithides. Body oval; glabella pyriform, without lateral furrows, with inflated basal lobes; eyes small. Thorax with nine segments. Pygidium rounded, formed of about thirteen segments. Carboniferous Limestone. Ex. *G. seminiferus.*

Distribution of the Trilobita.

The Trilobites form one of the most important and striking features in the Palæozoic faunas; they occur first in the Lower Cambrian Beds, and reach their maximum in the Ordovician; they are still abundant in the Silurian, but become less important in the Devonian, and in the Carboniferous are represented by four genera only. In Europe they do not extend beyond the Carboniferous Limestone, but in North America one species of *Phillipsia* has been found in the Permian.

Already in the Cambrian period the Trilobites were represented by a great variety of forms, showing that even then the Order must have been of considerable antiquity, but at present no traces of the ancestors of the Cambrian forms have been found. It is in the Cambrian System that we meet with the largest, as well as the smallest,

Trilobite known—*Paradoxides* and *Agnostus*. As a whole it may be said, that the Trilobites of the earlier formations are characterised by the possession of a large number of segments in the thorax and by a small pygidium (fig. 99), whereas in the Tremadoc, and particularly in the Ordovician Rocks, they possess large pygidia and have fewer segments in the thorax (fig. 100).

Many of the Trilobites seem to have had a wide geographical distribution; for example most of the genera which have been recognised in Australia occur also in Europe. Some, however, apparently had a more limited range; thus for example *Sao*, *Arethusina*, and *Ellipsocephalus*, are very common in Bohemia, but the first two have not been found in the British Isles, and the last has been recorded only once.

The most important genera in the different systems are mentioned below; those marked with an asterisk * are found only in one system.

Cambrian. *Agnostus*, *Microdiscus**, *Paradoxides**, *Olenellus*, *Olenus**, *Sao**, *Ellipsocephalus**, *Conocoryphe**, *Niobe*, *Asaphus*, *Angelina**.

Ordovician. *Agnostus*, *Ogygia*, *Ampyx*, *Trinucleus**, *Illænus*, *Asaphus*, *Æglina**, *Calymene*. *Ogygia*, *Asaphus*, *Trinucleus* and *Ampyx* are abundant; the last being almost confined to this System.

Silurian. *Phacops*, *Homalonotus*, *Calymene*, *Acidaspis*, *Cheirurus*, *Proetus*, *Illænus*, *Lichas*. *Phacops* and *Acidaspis* are particularly abundant.

Devonian. *Phacops*, *Homalonotus*, *Cheirurus*, *Bronteus*.

Carboniferous. *Phillipsia*, *Griffithides**, *Brachymetopus**.

ORDER III. OSTRACODA.

The Ostracods are generally minute. The body is not segmented and is usually compressed laterally and completely enclosed in a bivalved shell or carapace, which may be horny or calcareous; one valve is placed on each side of the animal. Dorsally the two valves are joined together by means of an elastic ligament which serves to open the shell; an adductor muscle passes from the interior of one valve to the other. There are seven pairs of appendages which can be protruded when the shell is opened. In some of the marine forms the shell is notched anteriorly so as to allow the antennæ to pass through when the shell is closed. The head carries two pairs of antennæ, one of mandibles, and two of maxillæ. The thorax has two or three pairs of appendages, which are not leaf-like. The abdomen is rudimentary and is without appendages; it terminates either in a fork or in a spiny plate. Respiration takes place by means of the general surface of the body. The carapace is in almost all cases the only part which occurs fossil; its surface may be smooth or variously ornamented.

Leperditia. Carapace thick, smooth, convex, elongated, a little wider posteriorly. The right valve larger than the left. Hinge-line straight. There is a small tubercle (eye-spot) placed anteriorly near the hinge; and posterior to it is a slightly elevated circular area. Cambrian to Carboniferous. Ex. *L. hisingeri*, Silurian; *L. okeni*, Carboniferous.

Primitia. Carapace generally equivalve, convex, oblong. Hinge-line straight. Each valve has a trans-

verse groove which starts from the hinge-line. Cambria to Carboniferous. Ex. *P. strangulata*, Bala Beds.

Beyrichia (fig. 102). Carapace elongated, inflated posterior border a little wider than the anterior; dorsal border straight, ventral border semicircular. On the surface there are two or three large furrows which pass from the dorsal towards the ventral edge, the parts between being convex and often tuberculate. Cambrian to Devonian. Ex. *B. complicata*, Llandeilo and Bala Beds.

Fig. 102. *Beyrichia complicata*, Bala Beds. The lower figure shows the dorsal aspect of the united valves. Enlarged.

Entomis. Carapace equivalve, almond-shaped, with a deep transverse furrow which passes from the dorsal border (a little in front of the middle) towards the ventral border. Surface smooth or striated. Anterior margin notched for the passage of the antennæ. Ordovician to Carboniferous. Ex. *E. tuberosa*, Silurian.

Cypris. Carapace thin, smooth or punctate, kidney-shaped or oval; ventral edge often concave. Left valve the larger. Purbeck Beds to present day. Freshwater. Ex. *C. faba*, Miocene; *C. gibba*, Oligocene to present day.

Cypridea. Valves ovate-oblong, convex in the middle, broad at the anterior third, narrower behind, with a notch at the anterior-ventral angle behind a beak-like process. Surface smooth, punctate, or tuberculate. Hinge margin straight along the middle third of the dorsal edge. Left valve the larger. Purbeck, Wealden, and Hamstead Beds. Freshwater. Ex. *C. valdensis*, Wealden Beds, etc.

Distribution of the Ostracoda.

The Ostracods have a very wide distribution at the present day; they are mainly marine, and often occur in shoals. They are most abundant in shallow water, only fifty-two species being found below the 500 fathom line. The fossil forms are very numerous, the earliest occurring in the Cambrian. *Leperditia*, *Primitia*, and *Beyrichia* are abundant in the Lower Palæozoic; *Entomis* in the Devonian; and *Cypridina* and *Bairdia* in the Carboniferous. *Cypridea* is common in the Purbeck and Wealden Beds; and *Cythere* in the Tertiary formations.

ORDER V. CIRRIPEDIA.

The Cirripedes include the barnacles, acorn-shells, etc., forms which differ considerably in appearance from the other crustaceans, and which were for a long time regarded as mollusks. The body is completely enclosed in a fold of the integument, which commonly forms a calcareous shell. The animal, in the adult state, is fixed to a foreign object by the anterior end of the head, either directly or by means of a stalk or peduncle. The segmentation of the body is indistinct. The head is not well-marked off from the thorax; it bears one or two pairs of antennæ, one pair of mandibles, and two pairs of maxillæ. The thorax has usually six pairs of biramous feathery limbs. The abdomen is rudimentary and without

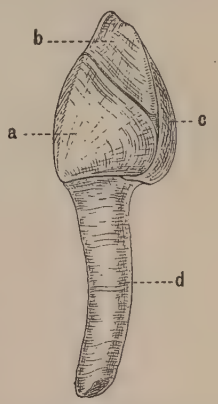


Fig. 103. *Lepas australis*, Recent. *a*, scutum; *b*, tergum; *c*, carina; *d*, peduncle. Natural size. (After Darwin.)

appendages. Heart and vascular system are absent; nearly all forms are hermaphrodite. The shell consists of several pieces; in *Lepas* (which possesses a stalk) there are five, two are placed on each side of the body, those near the stalk being termed the *scuta* (fig. 103 *a*), those at the upper end the *terga* (*b*), and there is also one unpaired part placed dorsally, the *carina* (*c*). *Balanus* has no stalk; its shell consists of a tube formed of six pieces within which the scuta and terga are placed.

Distribution of the Cirripedia.

The Cirripedes are all marine, and the greater number are found in shallow water, particularly near the coasts. *Balanus* is especially characteristic of littoral regions. At a depth greater than 1000 fathoms, only two genera, *Scalpellum* and *Verrucosa*, have been found, but these are not confined to deep water. The earliest genus is *Turrilepas* (= *Plumulites*), which ranges from the Ordovician to the Devonian. *Pollicipes* commences in the Rhætic, *Scalpellum* in the Cretaceous, and *Balanus* in the Eocene; all three are still living.

B. MALACOSTRACA.

The Malacostraca are of large or moderate size and are more highly organised than the Entomostraca. With the exception of the Leptostraca, the number of segments is constant throughout the group, there being five in the head, eight in the thorax, and six in the abdomen; each segment bears one pair of appendages. In some cases the development is direct, in a few the Nauplius stage occurs but more commonly the Zoæa larva is found.

There are three Orders:—(1) Leptostraca, (2) Thoracostraca, (3) Arthrostraca.

ORDER I. LEPTOSTRACA (PHYLLOCARIDA).

This Order forms a transition between the Phyllopoda and the Malacostraca; in the Palæozoic formations it is represented by numerous examples, but only three genera are now living, the most important being *Nebalia*. These forms are provided with a large carapace which is usually bivalved and covers the thoracic and some of the abdominal segments; in front it possesses a movable rostrum. In the existing forms there are twenty-one segments in the body—five in the head, eight in the thorax, eight in the abdomen, the last segment carrying two pointed processes. There are nineteen pairs of appendages, as in the Malacostraca: the head bears two pairs of antennæ, one pair of mandibles, two of maxillæ; on the thorax there are eight pairs of leaf-like limbs similar to those of the Phyllopods; the abdomen has six pairs of appendages, the first four being large, the last two small. The two posterior segments are without appendages—in the Palæozoic forms the last often bears several spines. The eyes are compound and stalked. The appendages of the fossil examples are very imperfectly known.

Hymenocaris (fig. 104). Carapace semi-oval, smooth, not bivalved. Abdomen formed of eight segments and four, five, or six, caudal spines. Appendages unknown. Lingula Flags. Ex. *H. vermicauda*.

Fig. 104. *Hymenocaris vermicauda*, from the Lingula Flags. One-half natural size.

Ceratiocaris. Carapace bivalved, often marked with striæ, oval, truncated behind and with a lanceolate rostrum in front. Body formed of

fourteen or more segments, the first seven or more being covered by the carapace; the last segment is produced into a strong spine and provided with two smaller spines. Tremadoc Beds to Carboniferous. Ex. *C. stygia*, *C. papilio*, Ludlow Beds.

Fig. 105. *Caryocaris wrighti*, from the Arenig Rocks. Natural size. The abdomen has *not been found* attached to the carapace as shown above; some authors consider that the broad end of the carapace is anterior.

Caryocaris (fig. 105). Carapace bivalved, pod-like, narrow, smooth, rounded at one end (probably the posterior), truncated at the other. Arenig Rocks. Ex. *C. wrighti*.

Distribution of the Leptostraca.

The three living genera are all marine. In Britain the earliest representative is *Hymenocaris*, which is found in the Lingula Flags; *Ceratiocaris* occurs in the Tremadoc Beds and ranges on to the Carboniferous, but is most abundant in the Silurian. *Echinocaris* is found in the Devonian; and *Dithyrocaris* in the Carboniferous.

ORDER II. THORACOSTRACA.

In this Order there is a cephalothorax formed by the fusion of the head with some or all of the segments of the thorax, and this is covered dorsally by a shield or carapace. There are thirteen segments in the head and thorax, six in the abdomen and a terminal telson. The eyes are compound and are usually placed on movable stalks.

The Thoracostraca include four sub-orders:—(1) Cumacea, (2) Stomatopoda, (3) Schizopoda, (4) Decapoda. The Cumacea are unknown in the fossil state.

SUB-ORDER II. STOMATOPODA.

In the Stomatopoda the cephalothoracic shield is short and does not cover all the thoracic segments. There are five pairs of maxillipedes. The three posterior segments of the thorax possess biramous appendages. The abdomen is much larger than the anterior portion of the body and its appendages bear gills.

Squilla is the best known genus of this group. All the forms are marine and they live in shallow water. The Stomatopods are very rare as fossils. A few Crustacea found in the Coal Measures (*e.g. Necroscylla*) have been referred to this Sub-Order; but undoubted representatives, allied to the existing *Squilla*, occur in the Solenhofen Limestone (Upper Jurassic). *Squilla* itself has been found in the Chalk of Lebanon and in some of the Eocene formations (London Clay, etc.).

SUB-ORDER III. SCHIZOPODA.

This Sub-Order is not known with certainty to occur in the fossil state; but alleged representatives of it have been recorded from the Coal Measures and the Solenhofen Limestone (Upper Jurassic).

SUB-ORDER IV. DECAPODA.

The Decapods include the lobsters (fig. 106), the crayfishes, the crabs, etc. The head, and in almost all cases all the segments of the thorax, are covered by the large and usually strong cephalothoracic shield (*a*—*c*); this is frequently marked out into an anterior and a posterior portion by a groove,—the *cervical suture* (*b*), the anterior part belonging to the head, the posterior to the thorax.

The shield in front is produced into a spine, the rostrum (*a*). The gills are placed in a chamber formed by the downward prolongation of the cephalothoracic shield. The

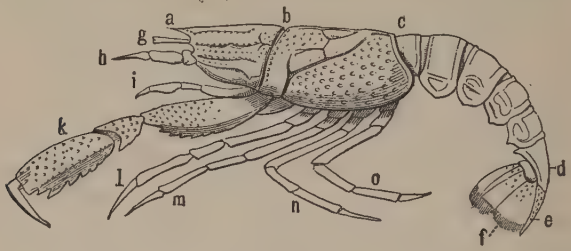


FIG. 106. *Glyphea regleyana*, Oxford Clay. *a*—*c*, cephalothorax; *a*—*b*, head; *b*—*c*, thorax; *a*, rostrum; *c*—*e*, abdomen; *d*, last abdominal segment; *e*, telson; *f*, appendage of last abdominal segment; *g*, eye; *h*—*o*, appendages of cephalothorax; *k*, *l*, *m*, *n*, *o*, ambulatory limbs. Two-thirds natural size.

cephalothorax bears thirteen pairs of appendages, five belonging to the head, eight to the thorax. On the head there are (1) antennules, (2) antennæ, (3) mandibles, (4 and 5) maxillæ; the last three pairs serve as jaws. On the thorax the three first pairs of limbs, known as *maxillipedes*, function in locomotion and also in mastication; the posterior five pairs are the ambulatory limbs; they are uniramous and consist of seven joints, and some of them terminate in pincers or *chelæ*. The abdomen bears six, or fewer, pairs of small appendages.

The Decapoda are divided into two sections:—(1) Macrura, (2) Brachyura.

Section 1. *Macrura.*

This section includes the lobsters and crayfishes. The abdomen is long, well-developed, and provided with four or five pairs of appendages. There is a large caudal fin

formed by the telson and the appendages of the last segment.

Eryon. Cephalothorax flattened, broader than long, with a median dorsal ridge on the posterior part; the lateral margins usually dentate, and at the anterior third are deep notches. Rostrum short. The first four pairs of ambulatory limbs on the thorax bear chelæ, those of the anterior pair being larger than the others. Abdomen of about the same length as the cephalothorax; the first segment very short. Telson trigonal. Lias to Cretaceous. Ex. *E. antiquus*, Lias; *E. propinquus*, Solenhofen Limestone (Upper Jurassic).

Glyphea (fig. 106). Cephalothorax ornamented with granules, provided with a median groove on the dorsal surface; rostrum short. In front of the cervical suture are several spiny or tuberculate parallel ridges which extend towards the anterior margin. Posterior to the cervical suture are generally two other grooves. The anterior pair of ambulatory limbs are much longer than the others. Abdomen long. Trias to Cretaceous. Ex. *G. regleyana*, Oxford Clay; *G. tenuis*, Solenhofen Limestone (Upper Jurassic).

Meyeria. Cephalothorax greatly compressed laterally, with a sharp rostrum, and a deep V-shaped cervical suture; the posterior part of the cephalothorax covered with sharp granules. Abdomen semi-cylindrical, longer than the cephalothorax, and ornamented with rows of granules. Lower Greensand. Ex. *M. magna*.

Eryma. Body cylindrical. Cephalothorax covered with granules, with a median dorsal groove and a deep cervical suture. Behind the cervical suture are two

nearly parallel grooves which unite at the sides. The three anterior pairs of ambulatory limbs with chelæ, the first pair being very large, the others small. Telson undivided. Lias to Upper Jurassic. Ex. *E. leptodactylina*, Solenhofen Limestone; *E. elegans*, Great Oolite etc.

Hoploparia. Body slightly compressed. Cephalothorax covered with fine granules. Rostrum very narrow, long, sharp, and not dentate. Cervical suture deep, not reaching the margins of the carapace; in front of the cervical suture is a λ-shaped groove. The two anterior pairs of ambulatory limbs large, provided with chelæ. Abdomen sub-cylindrical. Lower Cretaceous to Eocene. Ex. *H. longimana*, Lower Greensand.

Section 2. *Brachyura.*

This section includes the crabs. The abdomen is short and more or less rudimentary; it is curved up underneath the thorax, and bears from one to four pairs of appendages. There is no caudal fin.

Palæocorystes. Cephalothorax much longer than broad, tapering posteriorly, anterior border not dentate; rostrum short. Orbital cavities large with two small fissures. Cervical suture well defined. The five anterior segments of the abdomen short, the sixth quadrangular. Gault and Eocene. Ex. *P. stokesi*, Gault.

Xanthopsis. Cephalothorax rounded, convex, surface punctate, the posterior portion with rounded elevations; the frontal border with four, and the anterior-laterals with one to three, tooth-like processes. Orbital cavities deep, without fissures. Chelæ unequal. Abdomen of the male narrow and formed of five segments, owing to the

fusion of the third, fourth, and fifth segments. Abdomen of female broad, composed of seven segments. Eocene. Ex. *X. leachi*, London Clay.

Distribution of the Decapoda.

Most of the Decapoda are marine, the larger number living in shallow water. The Macrura are the first to appear in the geological series, a few genera being found in the Upper Palæozoic formations; the earliest is *Palæopalæmon* from the Upper Devonian; in the Carboniferous *Anthrapalæmon* and others occur. The section becomes much more abundant in the Mesozoic period, attaining its maximum in the Jurassic, where, amongst others, the genera *Glyphea*, *Eryon*, *Mecochirus*, *Æger*, and *Eryma* are found. In the Cretaceous, *Enoploclytia*, *Hoploparia* and *Meyeria* occur. Comparatively few forms are found in the Tertiary. A few examples found in the Upper Palæozoic rocks may belong to the Brachyura, but at present they are only imperfectly known; the group is represented by two or three genera (*e.g. Prosopon*, *Palæinachus*) in the Jurassic; in the Cretaceous by *Palæocorystes* and several others; in the Eocene numerous forms occur, *Xanthopsis* being the commonest genus; but the section attains its maximum at the present day.

ORDER III. ARTHROSTRACA.

There is no cephalothoracic shield; there are usually seven (sometimes fewer) free segments in the thorax; and usually six, and a telson, in the abdomen, but the abdomen may be rudimentary. In some genera one or two segments of the thorax have fused with the head. The head carries two pairs of antennæ, one of mandibles, two of

maxillæ, and one of maxillipedes. The thorax has seven and the abdomen six, pairs of appendages. The eyes are sessile. There are two Sub-orders:—(1) Amphipoda (2) Isopoda.

SUB-ORDER I. AMPHIPODA.

The Amphipods (*e.g. Gammarus*, *Talitrus*) are usually of small size, and the body is laterally compressed. There are seven segments in the thorax, the appendages of which bear the gills. The abdomen is usually elongate and carries six pairs of appendages; the three anterior serve for swimming, the three posterior for jumping. Some of the Amphipods are marine, others live in fresh water. The marine forms have a wide distribution, and are very numerous, especially in shallow water. The fossil forms are rare; *Necrogammarus* from the Lower Ludlow rocks of Leintwardine is probably an Amphipod; others—but of which the systematic position is a little uncertain—have been recorded from the Carboniferous and Permian, those found in the Tertiary formations belong mainly to genera which are still existing (*e.g. Gammarus* from the Miocene).

SUB-ORDER II. ISOPODA.

The body is flattened dorso-ventrally. In the thorax there are six or seven segments, each with a pair of ambulatory appendages. The abdomen is often short, and is formed of six segments (frequently fused) and a telson; some of its appendages function as gills. Many Isopods are marine, others are found in fresh water, whilst a few live on

FIG. 107. *Archæoniscus brodiei*, from the Purbeck Beds. Slightly reduced.

land (*e.g.* the wood-louse, *Oniscus asellus*); the fossil forms are rare. An imperfect specimen, from the Old Red Sandstone of Herefordshire, described under the name of *Prœarcturus gigas*, probably belongs to this group. *Arthropleura* occurs in the Coal Measures; *Cyclosphæroma* in the great Oolite; *Archæoniscus* in the Purbeck Beds; *Palœga* in the Cambridge Greensand, the Lower Chalk, and Foreign Tertiary; and *Eosphæroma* and other genera in the Oligocene.

CLASS III. MYRIAPODA.

The Myriapoda include the Millipedes, Centipedes, and allied forms. The body consists of a distinctly-marked head, and of segments which are similar in form and size, so that, externally, the limits of the thorax and abdomen cannot be defined; the segments are usually numerous. The head bears one pair of antennæ; and also mandibles and maxillæ. The segments behind the head (except the last) bear in some cases one, in others two, pairs of legs each; in the latter the segments are really double. The Myriapods breathe by means of tracheæ.

In the fossil state Myriapods are rare. Existing forms have been divided into two Orders:—(1) the *Chilopoda*, or centipedes, (2) the *Diplopoda*, or millipedes. The first undoubted representatives of the Chilopoda occur in the amber found in the Oligocene beds of Prussia; the Diplopoda have also been found mainly in this amber, but one form, which perhaps belongs to this Order, was discovered in the Cretaceous rocks of Greenland. The Palæozoic Myriapods differ considerably from the later representatives of the group and are regarded as constituting two distinct Orders which are confined to the

Palæozoic formations. The earliest examples belong to the genera *Kampecaris* and *Archidesmus*, and occur in the Old Red Sandstone of Scotland; a larger number of forms (*e.g. Xylobius, Euphoberia*) are found in the Carboniferous, and some are present in the Permian rocks.

CLASS IV. INSECTA.

The body of the Insects can be separated into head, thorax, and abdomen. The head is formed of fused segments; it bears four pairs of appendages—one pair of antennæ, one of mandibles, and two of maxillæ. In the thorax there are three segments, each bearing one pair of legs; the second and third segments usually carry a pair of wings on their dorsal surfaces. The abdomen is composed of several (commonly ten) segments, which do not bear limbs. Insects breathe by means of tracheæ.

The earliest Insect at present known (*Palæoblattina douvillei*) was found in the Silurian rocks of France. Others occur in the Devonian of North America. In the Coal Measures of some districts the group is represented by a considerable variety of forms. Remains of Insects have been found at many horizons in the Mesozoic and Cainozoic formations; in England they are fairly common in certain divisions of the Lias, the Purbeck, the Wealden, and the Bembridge Beds. They are well represented in the Solenhofen Limestone (Upper Jurassic) of Bavaria, in the Miocene of Oeningen in Switzerland, and particularly so in the amber of the Oligocene beds of Prussia.

The Insects found in the Palæozoic formations are considered by Scudder to be more generalised than the later forms. He regards them as constituting a distinct

Order; but by a careful study of better-preserved specimens Brongniart has shown that these early insects can all be placed in the Orders adopted for existing forms.

The Insecta include an enormous number of forms, and the specimens found fossil are usually very imperfectly preserved, so that nothing more than a brief sketch of the distribution of the chief groups can be attempted here.

The Class is divided into the following Orders:—

ORDER I. APTERA.

Examples of this Order, which contains small wingless forms such as *Lepisma*, the silver-fish, occur in the Coal Measures of Commentry; several have been found in amber from the Oligocene rocks.

ORDER II. ORTHOPTERA.

The Forficulidæ (earwigs) occur first in the Lias; others have been found in the Oligocene amber but they are not common. A representative (*Palæoblattina*) of the Blattidæ (cockroaches) has been found in the Silurian rocks, and others occur in the Coal Measures; they are found also in the Trias and are fairly common in the Jurassic; the Tertiary forms occur mainly in the Oligocene amber. Ancestors of the Locustidæ (locusts) and the Acridiidæ (grass-hoppers) are known first in the Coal Measures; a few forms belonging to these families have been obtained from the Jurassic and Tertiary deposits. The Gryllidæ (crickets) occur in the Lias, and several forms have been found in the Tertiary rocks.

ORDER III. NEUROPTERA.

The earliest examples of this Order occur in the Devonian; in the Coal Measures quite a variety of forms are met with. Termitidæ (white ants) have been discovered in the Lias, and in Tertiary rocks many examples have been found. Forms allied to the Ephemeridæ (may-flies) are present in the Coal Measures; others occur in the Solenhofen Limestone and in the Oligocene amber. The Libellulidæ (dragon-flies) have representatives in the Coal Measures, the Lias, the Solenhofen Limestone, and the Wealden; and some occur in the Tertiary formations. A few examples of the Phryganidæ (caddis-flies) are known from the Mesozoic rocks, and various forms exist in the Tertiary beds.

ORDER IV. LEPIDOPTERA.

Butterflies and moths are very rare as fossils. A few have been recorded from the Jurassic rocks; they are better represented, although still very uncommon, in the Tertiary beds.

ORDER V. COLEOPTERA.

The first Coleoptera (beetles) occur in the Trias; they are more numerous in the Jurassic, and are well represented in some of the Tertiary beds.

ORDER VI. HEMIPTERA.

Some forms have been recorded from the Upper Palæozoic rocks. Examples of the Aphididæ (plant-lice) are found in the Wealden strata, and there are many forms in the Tertiary. The Cicadidæ occur in the Lias

and are abundant in the Tertiary. The Notonectidæ (water-bugs) appear in the Tertiary rocks.

ORDER VII. DIPTERA.

The Diptera include flies, fleas, gnats, and mosquitoes. A few forms are found in the Lias, the Solenhofen Limestone, and the Purbeck Beds; the Order is represented by numerous forms in the Tertiary strata.

ORDER VIII. HYMENOPTERA.

This Order includes the ants, bees, and wasps. One form has been found in the Lias, a few occur in the Solenhofen Limestone and the Purbeck Beds; a larger number are met with in the Tertiary rocks.

CLASS V. ARACHNIDA.

Common forms of Arachnids are the scorpions, the spiders, and the mites. In the members of this Class the segments of the head and thorax have generally fused together, forming a cephalothorax. This region of the body usually bears six pairs of appendages; antennæ are absent; the first and second pairs—known as *chelicerœ* and *pedipalpi*—end in chelæ, and serve as jaws; the four remaining pairs are long limbs which are used for locomotion and are placed behind the mouth. The abdomen may or may not be segmented; in some groups it is divided into an anterior and a posterior region. The appendages of the abdomen are never in the form of locomotory limbs. The Arachnids breathe by means of lung-books, tracheæ, or branchiæ.

ORDER I. XIPHOSURA[1].

The only living representative of the Xiphosura is *Limulus*, the king-crab (fig. 108), found on the eastern shores of North America and Asia, and in the Malay Archipelago. The body is protected by a chitinous shell which shows a fairly well marked division into three

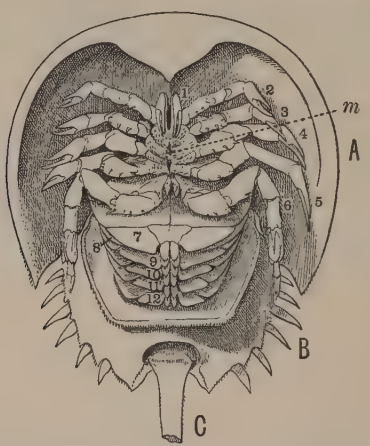


FIG. 108. *Limulus polyphemus*, Recent. *A*, cephalothorax. *B*, abdomen *C*, portion of the caudal spine. 1—6, appendages of the cephalothorax; 1, cheliceræ, 2, pedipalpi; 3—6, ambulatory legs; 7—12 appendages of the abdomen; 7, operculum; 8—12, lamellæ bearing gills. *m*, mouth. Reduced.

lobes; the cephalothorax is covered dorsally by a large crescent-shaped shield (*A*), which is very convex above and carries on its upper surface two pairs of eyes, one compound, the other simple (termed *ocelli*). The compound eyes are placed near the middle of the lateral part of the cephalothorax; the simple eyes are close together

[1] Some authors include the Xiphosura and the Eurypterida in one group—the *Merostomata*.

near the anterior margin. Behind the cephalothorax, and movably articulated with it, is the abdominal shield; this is composed of seven fused segments, the segmentation being shown by grooves; at the sides it bears movable spines, and posteriorly it is provided with a long caudal spine. The cephalothorax carries six pairs of appendages on its under surface, the anterior pair (cheliceræ) only being placed in front of the mouth. The other five pairs are much longer and are placed at the sides of the mouth; their basal joints function in mastication. The abdomen carries six pairs of appendages; the anterior pair, forming what is known as the *operculum* (7), are plate-like and have the genital openings on their posterior surfaces. The operculum covers the remaining five pairs; these bear the gills, which consist of a large number of thin plates.

The earliest Xiphosurans (*Hemiaspis, Neolimulus, Bunodes*) are found in the Silurian rocks; in the Carboniferous, *Prestwichia, Belinurus* and others occur. *Limulus* appears first in the Trias. The Palæozoic genera differ in some respects from the later ones; the head-shield is not fused with the thoracic shield, and the former sometimes shows a facial suture (*e.g. Hemiaspis, Neolimulus*); generally also, some or all of the segments of the thorax and abdomen remain free and movable. Thus in the *Hemiaspis* (fig. 109) there are six segments in the thorax and three in the abdomen, all of which are free; in *Belinurus* there are five free thoracic segments and three fused abdominal ones; in *Prestwichia* all the segments of both thorax and abdomen are fused.

Fig. 109. *Hemiaspis limuloides*, from the Lower Ludlow Beds. $\times \frac{1}{2}$.

ORDER II. EURYPTERIDA.

The Eurypterids are quite extinct and form a very remarkable group of the Arthropoda; they are usually o large size, some examples having a length of several feet

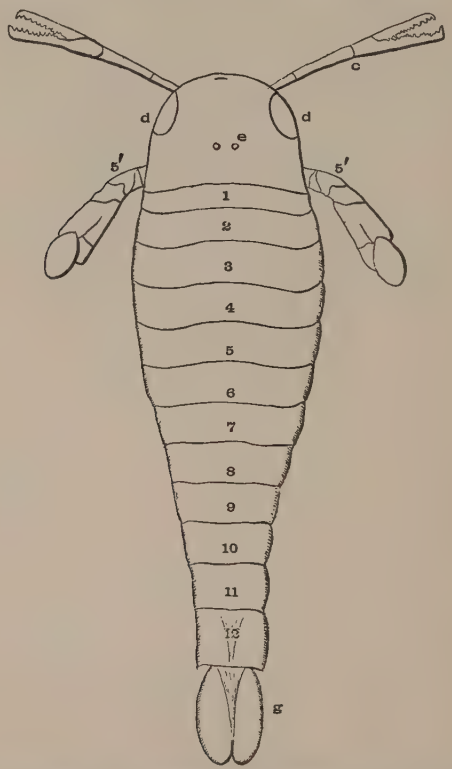


Fig. 110. Dorsal surface of *Pterygotus osiliensis*, from the Upper Silurian Rootziküll. *c*, first pair of appendages; *d*, compound eyes; *e*, ocelli *g*, telson; 5′, sixth pair of appendages; 1—6, segments of th abdomen; 7—12, segments of the post-abdomen. Reduced. (Afte Schmidt.)

trilobation is either absent or only very faintly indicated. The body is protected by a chitinous skeleton (fig. 110), the anterior part (cephalothorax) consisting of a large quadrate or semicircular shield; this is followed posteriorly

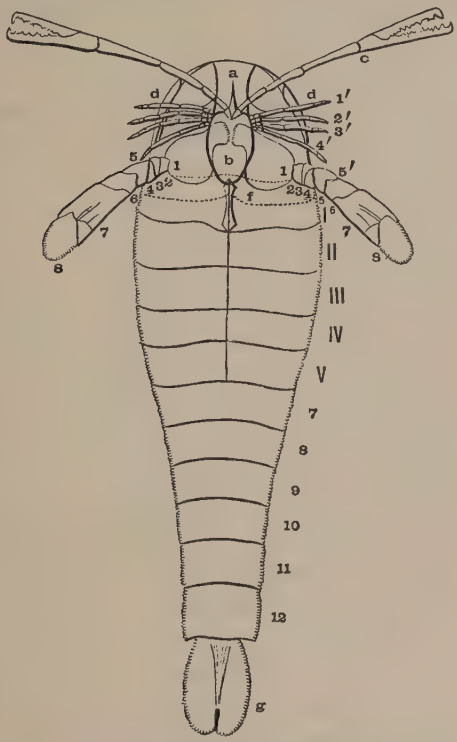


Fig. 111. Ventral surface of *Pterygotus osiliensis*, from the Upper Silurian, Rootziküll. *a*, epistome; *b*, metastoma; *c*, first pair of appendages; *d*, compound eyes; *f*, operculum; *g*, telson; 1′—5′, second to sixth pairs of appendages; I.—V., ventral plates of the abdomen; 7—12, segments of the post-abdomen. Reduced. (After Schmidt.)

by twelve free and movable segments which taper towards the posterior extremity. The first six free segments (1—6)

are regarded as the abdomen, and the remaining six (7—1
as the post-abdomen ; behind the last segment is the telso
(*g*),—an oval and sometimes pointed plate. The ceph
lothoracic shield carries on its upper surface two pai
of eyes; a large compound pair (*d*) placed lateral
or at the anterior angles, and a pair of simple eyes
ocelli (*e*) placed close together near the centre of th
shield. The mouth is on the under surface of the ceph
lothorax (fig. 111); in front of the mouth there is on
pair of appendages only (*c*), and they often end in chela
the other five pairs of appendages (1′—5′) consist of seve
or eight joints each, and are sometimes chelate ; they fun
tioned both in locomotion and in mastication, the bas
joints being provided with tooth-like processes; the po
terior pair (5′) are often very much larger than the other
Placed just behind the mouth, in the median line, is a
oval or heart-shaped plate—the *metastoma* (*b*). Th
shields which cover the dorsal surfaces of the six segmen
of the abdomen are not continued round on the ventr
surface as would at first sight appear to be the cas
but there are instead, five plate-like structures (I.—V
which cover the leaf-like gills (fig. 112 *c*); the first, know
as the operculum, consists of a pair of plates with a media
process, and corresponds with the operculum of *Limulu*
The segments of the post-abdomen (fig. 111, 7—12) a
protected by continuous rings and bear no appendages.

The Eurypterids agree with the Xiphosura in ma
points, but differ in the abdominal segments being alwa
free, in the possession of a metastoma, and in the absen
of trilobation.

Eurypterus. Cephalothoracic shield quadrate, t
anterior angles rounded; the compound eyes are not
the margin, but a little in front of the median late

point on each side. The telson is greatly elongated. The pre-oral appendages are small and not chelate; of the other pairs of appendages the fifth are longer than the preceding, and the sixth pair are still longer and also larger. The metastoma is oval. Lower Ludlow to Carboniferous. Ex. *E. scorpioides*, *E. fischeri*, Upper Silurian; *E. scouleri*, Carboniferous.

Stylonurus. Form similar to *Eurypterus*, but the two posterior pairs of appendages are very long and slender. Upper Silurian, and Old Red Sandstone. Ex. *S. powriei*, same range.

Pterygotus (figs. 110, 111). Cephalothoracic shield rounded in front; the compound eyes are marginal, and placed at the anterior angles. The telson is oval and either bilobed or pointed at its extremity. The pre-oral appendages are long and chelate; the sixth pair long and stout. Metastoma oval. The examples of this genus

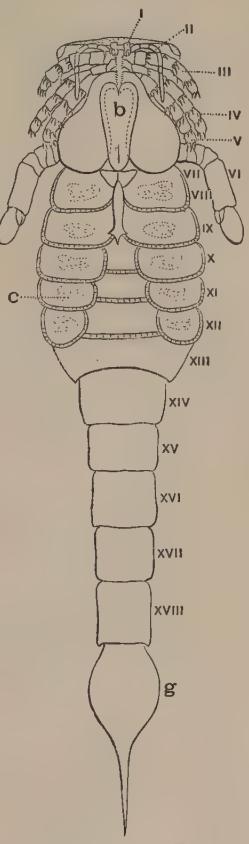


Fig. 112. *Slimonia*. Restoration of the under surface by M. Laurie. *b*, metastoma; *c*, leaf-like gills seen through the ventral plates of the abdomen; *g*, telson; I.—VI. appendages of the cephalothorax; VII.—XIII., segments of the abdomen; XIV.—XVIII., segments of the post-abdomen. Reduced.

are usually of enormous size, *P. anglicus* sometimes reach ing a length of nearly six feet. Lower Ludlow to Ol Red Sandstone. Ex. *P. anglicus*, Old Red Sandstone *P. bilobus*, Upper Silurian.

Slimonia (fig. 112). Cephalothoracic shield quadrate the compound eyes at the anterior angles. Segments c the abdomen much larger than those of the post abdomen. The telson is oval, ending in a point. Meta stoma heart-shaped. The pre-oral appendages (cheliceræ are small and chelate; the second pair of appendage are slender, composed of six joints, and are not chelate The third, fourth, and fifth pairs are seven jointed and similar in size and form. The sixth pair are longe and have a very large basal joint. Upper Ludlow an Passage beds. Ex. *S. acuminata*, uppermost beds of th Silurian.

Distribution of the Eurypterida.

The Order ranges from the Ordovician to the Permian and is most abundant in the Upper Silurian and the Old Red Sandstone. The chief genera are *Eurypterus, Ptery gotus, Slimonia*, and *Stylonurus.*

The remaining Orders of the Arachnida are but poorly represented in the fossil state; their general distribution is briefly indicated below.

ORDER III. SCORPIONIDA.

The earliest scorpions, represented by the genera *Palæophonus* and *Proscorpius*, are found in the Silurian rocks of Gothland, Scotland, and North America. *Eoscor pius* is present in the Carboniferous, and one form is known in the Oligocene beds.

ORDER IV. PSEUDOSCORPIONIDA.

This Order includes the book-scorpions (*Chelifer cancroides*) and others. Various forms, belonging to existing genera, occur in the Oligocene amber, *e. g. Chelifer*, *Chernes.*

ORDER V. PEDIPALPI.

The scorpion-spiders are represented by two forms in the Carboniferous and one in the Tertiary rocks.

ORDER VI. ARANEIDA.

Spiders belonging to the genera *Protolycosa* and *Palaranea* are found in the Coal Measures. In the Oligocene amber a large number of forms occur.

ORDER VII. PHALANGIDA (or Opilionina).

The examples of this Order are commonly known as 'harvest-men'; they have only yet been found fossil in the Oligocene amber.

ORDER VIII. ACARINA.

This comprises the mites and ticks. Various forms of mites occur in the Oligocene amber.

ORDER IX. ANTHRACOMARTI.

Examples of this Order have been found in the Carboniferous rocks only, *e.g. Architarbus, Anthracomartus.*

LIST OF PALÆONTOLOGICAL WORKS.

ABBREVIATIONS.

A. J. S.	American Journal of Science.
A. M. N. H.	Annals and Magazine of Natural History.
G. M.	Geological Magazine.
Q. J. G. S.	Quarterly Journal of the Geological Society.

GENERAL.

K. A. von Zittel. (1) Handbuch der Palæontologie. 4 vols. 1876–93. (There is a French translation by Barrois.) (2) Grundzüge der Palæontologie (Palæozoologie). 1895.

G. Steinmann and **L. Döderlein.** Elemente der Paläontologie. 1888–1890.

M. Neumayr. Die Stämme des Thierreiches. Vol. I. 1889.

F. McCoy. (1) British Palæozoic Fossils. 1851–55 [pp. 1–154, 1851; pp. 185–406, 1852; pp. 407 to end, 1855]. (2) Synopsis of the Carboniferous Limestone Fossils of Ireland. 1844. (3) Synopsis of the Silurian Fossils of Ireland. 1846.

R. I. Murchison. (1) The Silurian System. 1839. (2) Siluria ed. 5. 1872. [For Lower Palæozoic Fossils].

J. Phillips. (1) Geology of Yorkshire. 1829. [Carboniferous and Mesozoic fossils.] ed. 3 [Part I. Mesozoic]. 1875. (2) Palæozoic Fossils of Cornwall, Devon, etc. Mem. Geol. Survey. 1841.

G. F. Whidborne. Devonian Fauna of the South of England. 1889– . (Palæont. Soc.)

C. Barrois. Faune du Calcaire d'Erbray. [Devonian.] Mém. Soc. géol. du Nord. Vol. III. 1889.

C. D. Walcott. The Fauna of the Lower Cambrian or Olenellus zone. 1890. (Ann. Rep. U. S. Geol. Survey.)

F. Dixon. Geology of Sussex. ed. 2. 1878. [Cretaceous and Tertiary.]

G. Mantell. Fossils of the South Downs. 1822. [Cretaceous.]

CATALOGUES OF FOSSILS.

J. Morris. Catalogue of British Fossils. Second edition. 1854.

R. Etheridge. Fossils of the British Islands. Vol. I. Palæozoic. 1888.

J. J. Bigsby. (1) Thesaurus Siluricus. 1868. (2) Thesaurus Devonico-Carboniferus. 1878.

H. G. Bronn. Index Palæontologicus. 1848.

R. Etheridge, jun. Catalogue of Australian Fossils. 1878.

S. A. Miller. (1) American Palæozoic Fossils. 1877. (2) North American Geology and Palæontology. 1889.

FORAMINIFERA.

W. B. Carpenter. Introduction to the Study of the Foraminifera. 1862. (Ray Society.)

H. B. Brady. (1) Report on the Foraminifera. (Challenger Report) 1884. (2) A Monograph of Carboniferous and Permian Foraminifera. 1876. (Palæont. Soc.)

T. R. Jones, W. K. Parker, and **H. B. Brady.** A Monograph of the Foraminifera of the Crag. Part I. 1866. Part II. by T. R. Jones, 1895. (Palæont. Soc.)

T. R. Jones. Catalogue of the Fossil Foraminifera in the British Museum. 1882.

C. D. Sherborn. (1) A Bibliography of the Foraminifera. 1888. (2) An Index to the Genera and Species of the Foraminifera. Part I. 1893. Part II. 1896. (Smithsonian Miscell. Collections.)

F. Chapman. Foraminifera of the Gault of Folkestone. Journ. Roy. Micro. Soc. (1891), p. 565; (1892), pp. 319, 749; (1893), p. 579; (1894), pp. 153, 421.

RADIOLARIA.

E. Haeckel. (1) Die Radiolarien. 1862. (2) Report on the Radiolaria. (Challenger Report) 1887.

G. J. Hinde. (1) Notes on Radiolaria from the Lower Palæozoic Rocks (Llandeilo-Caradoc) of the South of Scotland. A. M. N. H. ser. 6, Vol. VI. (1890), p. 40. (2) Radiolaria in the Mullion Island Chert. Q. J. G. S. Vol. XLIX. (1893), p. 215. (3) and **H. Fox,** Radiolarian Rocks in the Lower Culm Measures, *ibid.* Vol. LI. (1895), p. 609.

Rüst. Radiolarien. Palæontographica. (Jurassic) Vol. XXXI. (1885), p. 269; (Chalk) Vol. XXXIV. (1888), p. 181; (Trias and Palæozoic) Vol. XXXVIII. (1892), p. 107.

W. Hill and **A. J. Jukes-Browne.** Radiolaria in Chalk. Q. J. G. S. Vol. LI. (1895), p. 600.

C. E. Grimes. Radiolarians in English Cretaceous Rocks. G. M. (1895), p. 345.

W. H. Shrubsole. Radiolaria of the London Clay. Q. J. G. S. Vol. xlv. (1889), p. 121.

L. Cayeux. Les preuves de l'existence d'organismes dans le Terrain Pré-cambrien. Bull. Soc. géol. France, sér. 3, Vol. XXII. (1894), p. 197. Also notice in G. M. (1894), p. 419.

H. Rauff. Ueber angebliche Organismenreste aus präcambrischen Schichten der Bretagne. Neues Jahrb. für Min. etc., Vol. I. (1896), p. 116.

PORIFERA.

G. C. J. Vosmaer. Porifera, in Bronn's Klassen und Ordn. des Thierreichs, Vol. II. 1887.

R. v. Lendenfeld. Monograph of the Horny Sponges. Royal Soc., 1889.

W. J. Sollas. (1) On the structure and affinities of the Genus *Siphonia*. Q. J. G. S. Vol. XXXIII. (1877), p. 790. (2) Tetractinellida (Challenger Report). 1888.

F. E. Schultze. Hexactinellida (Challenger Report). 1887.

N. E. Polejaeff. Calcarea (Challenger Report). 1883.

S. O. Ridley and **A. Dendy.** Monaxonida (Challenger Report). 1887.

G. J. Hinde. (1) Catalogue of the Sponges in the Geological Department of the British Museum (Natural History). 1883. (2) A Monograph of British Fossil Sponges. 1887– . (Palæont. Soc.)

H. Rauff. (1) Palæospongologie. Palæontographica, Vol. XL., 1893–4; XLI. (1895), p. 223. (2) Ueber die Organisation und systematische Stellung der Receptaculitiden. Abhandl. der math.-phys. Classe d. k. bayer. Akad. Vol. XVII. (1892), p. 645.

HYDROZOA.

C. Lapworth. (1) On the geological distribution of the Rhabdophora. A. M. N. H. ser. 5, Vol. III. (1879), pp. 245, 449; Vol. IV. (1879), pp. 333, 423; Vol. V. (1880), pp. 45, 273, 358; Vol. VI. (1881), pp. 16, 185. (2) On an improved classification of the Rhabdophora, G. M. Vol. X. (1873), pp. 500, 555. (3) On Scottish Monograptidæ. G. M. dec. 2, Vol. II. (1876), pp. 308, 350, 499, 544. (4) On new British Graptolites. A. M. N. H. ser. 5, Vol. V. (1880), p. 149.

J. Hopkinson and **C. Lapworth.** Descriptions of the Graptolites of the

Arenig and Llandeilo Rocks of St David's. Q. J. G. S. Vol. xxxi. (1875), p. 631.

H. A. Nicholson. A Monograph of the British Graptolitidæ. Part I. General Introduction. 1872.

J. Hall. Graptolites of the Quebec group. (Figures and descriptions of Canadian Organic Remains. dec. II.) 1865.

J. Hopkinson. Morphology of the Rhabdophora. A. M. N. H. ser. 5, Vol. IX. (1882), p. 54.

O. Hermann. (1) Distribution of the Graptolithidæ. G. M. (1885), p. 406. (2) Organisation and Economy of Graptolithidæ, *ibid.* p. 448. (3) The Dichograptidæ, *ibid.* (1886), p. 13.

G. Holm. On *Didymograptus*, *Tetragraptus*, and *Phyllograptus*. G. M. (1895), pp. 433, 481.

H. A. Nicholson and **J. E. Marr.** Phylogeny of the Graptolites. G. M. (1895), p. 529.

R. Ruedman. Mode of Growth and Development of *Diplograptus*. A. J. S. ser. 3, Vol. XLIX. (1895), p. 453.

S. L. Törnquist. Structure of Diprionidæ. Särtryck af Konl. Fysiogr., Handl. Ny Följd, Vol. IV. 1893.

C. Wiman. Ueber Diplograptidæ. Ueber Monograptidæ. Bull. Geol. Inst. Upsala, Vol. I. (1894), pp. 97, 113.

J. Perner. Études sur les Graptolites de Bohême. Part I., 1894. Part II., 1895.

J. Barrande. Graptolites de Bohême. 1850.

O. Jaeckel. Ueber das Alter des sog. Graptolithengesteines etc. Zeitschr. der deutsch. geol. Gesellsch. Vol. XLI. (1889), p. 653.

H. A. Nicholson. A Monograph of the British Stromatoporoidea. 1886–1892. (Palæont. Soc.)

ACTINOZOA.

G. Brook. Catalogue of Madreporarian Corals in the British Museum. Vol. I. 1893.

H. Milne Edwards. Histoire naturelle des Coralliares. 1857–60.

J. J. Quelch. Report on the Reef Corals (Challenger Report). 1886.

E. P. Wright and **T. Studer.** Alcyonaria (Challenger Report). 1889. Supplement, 1889.

H. N. Moseley. Helioporidæ. (Challenger Report, Vol. II. p. 102.) 1881.

E. de Fromentel. Introduction à l'étude des Polypiers fossiles. 1858–61.

H. A. Nicholson. (1) On the structure and affinities of the "Tabulate Corals" of the Palæozoic Period. 1879. (2) On the structure and affinities of the Genus *Monticulipora* and its sub-genera. 1881 (3) *Tubipora musica*, and on the relation of *Tubipora* to *Syringopora* Proc. Roy. Soc. Edin., Vol. xi. (1880–81), p. 219. (4) and **J. Thomson.** Study of the chief types of Palæozoic Corals A. M. N. H. ser. 4, Vol. xvi. (1875), pp. 305, 424; xvii. (1876) pp. 60, 123, 290, 451; xviii. (1876), p. 68.

S. J. Hickson. Structure and Relations of *Tubipora*. Quart. Journ. Micr. Science, Vol. xxiii. (1883), p. 556.

M. M. Ogilvie. Microscopic and systematic study of Madreporarian Types of Corals. Proc. Roy. Soc., Vol. lix. (1896), p. 9.

A. Ortmann. Die Morphologie des Skelettes der Steinkorallen Zeitschr. für wiss. Zool., Vol. l. (1890), p. 278.

F. W. Sardeson. Ueber die Beziehungen der fossilen Tabulaten zu den Alcyonarien. Neues Jahrbuch für Min. etc. Beilage-Band x. (1896) p. 249.

C. E. Beecher. (1) The development of a Palæozoic Poriferous Coral Trans. Connecticut Acad., Vol. viii. (1893), p. 207. (2) Symmetrical Cell Development in the Favositidæ, *ibid.* p. 215.

G. Lindström. On the affinities of the Anthozoa Tabulata. A. M. N. H. ser. 4, Vol. xviii. (1876), p. 1.

H. M. Edwards and **J. Haime.** A Monograph of the British Fossil Corals. 1850–54. (Palæont. Soc.)

P. M. Duncan. (1) A Monograph of the British Fossil Corals. (Supplement to the preceding.) 1866–72. (Palæont. Soc.) (2) A Revision of the Families and Genera of the Sclerodermic Zoantharia, or Madreporaria. Journ. Linn. Soc. (Zool.) Vol. xviii. (1885), pp. 1–204.

G. J. Hinde. *Septastræa*. Q. J. G. S. Vol. xliv. (1888), p. 200.

C. Schlüter. Anthozoen des rheinischen Mittel-Devon. Abhandl. preuss. geol. Landes-Anst., Vol. viii., 1889.

C. Rominger. Geological Survey of Michigan. Lower Peninsula Vol. iii., Fossil Corals. New York, 1876.

F. Koby. (1) Monographie des Polypiers jurassiques de la Suisse (Mém Soc. Pal. Suisse) 1881–89. (2) Monographie des Polypiers crétacés de la Suisse (*ibid.*) 1896– .

W. H. Sherzer. Rugose Corals. Amer. Geol., Vol. vii. (1891), p. 273.

W. N. Dybowski. Monographie der Zoantharia Rugosa, etc. Arch. f. Naturk. Liv-, Est- und Kurlands. Vol. v., 1874.

E. J. Chapman. On the Corals and Coralliform Types of Palæozoic Strata. Trans. Roy. Soc. Canada, Vol. x. (1893), Section iv, p. 39.

ECHINODERMA.

H. Ludwig. Echinoderms in Bronn's Klassen und Ordnungen des Thierreichs. Edition 2. 1889.

W. P. Sladen. (1) Asteroidea (Challenger Report), 1889. (2) A Monograph of the British Fossil Echinodermata. Vol. II. Asteroidea. 1891– . (Palæont. Soc.)

E. Forbes. Asteriadæ in British Strata. (Mem. Geol. Survey. Organic Remains. dec. I.) 1849.

B. Stürtz. Beiträge zur Kenntniss palæozoischer Seesterne. Palæontographica, Vol. XXXII. (1886), p. 75; XXXVI. (1890), p. 203.

T. Lyman. Ophiuroidea (Challenger Report). 1882.

T. Wright. A Monograph on the British Fossil Echinodermata of the Oolitic Formations. Vol. I. Echinoidea. (1857–1878.) Vol. II., Asteroidea and Ophiuroidea (1863–1880). (Palæont. Soc.)

L. Agassiz. Monographie d'Echinodermes vivans et fossiles. 1838–41.

A. Agassiz. (1) Revision of the Echini. Mem. Mus. Comp. Zool. Vol. III., 1872–4. (2) Echinoidea (Challenger Report). 1881.

S. Lovén. Echinologica. Kongl. Svensk Vetenskaps-Akad. Handl. XVIII. (4), p. 1. 1892.

T. Wright. Monograph on the British Fossil Echinodermata from the Cretaceous Formations. Vol. I. Echinoidea. 1864–1882. (Palæont. Soc.)

P. M. Duncan. (1) Structure of the Ambulacra of some fossil Regular Echinoidea. Q. J. G. S. Vol. XLI. (1885), p. 419. (2) A Revision of the Genera and great Groups of the Echinoidea. Journ. Linn. Soc. (Zool.), Vol. XXIII. (1889), p. 1. (3) Anatomy of *Palæechinus*. A. M. N. H. ser. 6, Vol. III. (1889), p. 196.

E. Forbes. Monograph of the Echinodermata of the British Tertiaries. 1852. (Palæont. Soc.)

J. W. Gregory. A Revision of the British Fossil Cainozoic Echinoidea. Proc. Geol. Assoc., Vol. XII. (1891), p. 16.

R. Etheridge, jun. Echinothuridæ and Perischoechinidæ. Q. J. G. S. Vol. XXX. (1874), p. 307.

R. T. Jackson and **T. A. Jagger.** Studies of *Melonites*. Bull. Geol. Soc. America, Vol. VII. (1896), p. 135. **Jackson,** Studies of Palæechinoidea, *ibid.* p. 171.

E. Desor. Synopsis des Echinides fossiles. 1858.

A. D'Orbigny. Paléontologie française. Terr. crét., Vol. VI. Echinides irréguliers.

G. Cotteau. Terr. crét., Vol. VII. Echinides irréguliers (continuation

of above). Terr. jurassiques, Vol. IX. Echinides irréguliers. Vol. XI. Echinides réguliers.

R. Etheridge, jun. Holothuroidea in the Carboniferous. Proc. Roy. Phys. Soc. Edinburgh, Vol. VI. (1880–81), p. 183.

W. B. Carpenter. (1) *Antedon.* Proc. Roy. Soc., Vol. XXIV. (1876), p. 211. (2) *Comatula.* Phil. Trans., Vol. CLVI. (1866), p. 671.

P. H. Carpenter. (1) Crinoidea (Challenger Report). 1884, 1888. (2) On the Oral and Apical Systems of Echinoderms. Quart. Journ. Micr. Science, Vol. XVIII. (1878), p. 351; XIX. (1879), p. 176.

C. Wachsmuth and **F. Springer.** (1) Revision of the Palæocrinoidea. Proc. Acad. Nat. Sci., Philadelphia, 1879, p. 226; 1881, p. 177; 1885, p. 225; 1886, p. 64. (2) *Crotalocrinus, ibid.* 1888, p. 364.

L. de Koninck and **H. Le Hon.** Recherches sur les Crinoides du Terrain carbonifère de la Belgique. 1854.

L. von Buch. Ueber Cystideen. Abhandl. d. k. Akad. d. Wiss. zu Berlin (1844), p. 89.

F. A. Bather. (1) British Fossil Crinoids. A. M. N. H., ser. 6, Vol. V. (1890), pp. 306, 373, 485; Vol. VI. (1890), p. 222; Vol. VII. (1891), pp. 35, 389; Vol. IX. (1892), pp. 189–202. (2) Terms in Crinoid Morphology, *ibid.* Vol. IX. (1892), p. 51. (3) Crinoidea of Gothland. Part I. The Crinoidea Inadunata. K. Vet. Akad. Handl. (Stockholm), Vol. XXV. 1893. (4) *Uintacrinus.* Proc. Zool. Soc. 1895, p. 974.

E. Forbes. On the Cystideæ of the Silurian Rocks of the British Islands. (Mem. Geol. Survey, Vol. II., Part II.) 1848.

E. Billings. Cystideæ of the Lower Silurian Rocks of Canada. (Geol. Survey of Canada: Organic Remains, dec. III.) 1858.

J. Barrande. Système Silurien du centre de la Bohême. (Cystidées par **W. Waagen.**) Vol. VII. 1887.

P. H. Carpenter. Morphology of the Cystidea. Journ. Linn. Soc. (Zool.) Vol. XXIV. (1894), p. 1.

R. Etheridge and **P. H. Carpenter.** Catalogue of the Blastoidea in the Geological Department of the British Museum (Natural History). 1886.

CHÆTOPODA.

G. J. Hinde. (1) On Annelid Jaws from the Cambro-Silurian, Silurian, and Devonian Formations in Canada, and from the Lower Carboniferous in Scotland. Q. J. G. S., Vol. XXXV. (1879), p. 370. (2) On Annelid Jaws from the Wenlock and Ludlow Formations of the West of England. *ibid.* Vol. XXXVI. (1880), p. 368.

BRACHIOPODA.

P. Fischer. Manuel de Conchyliologie. 1887. [Brachiopods, by D. P. Œhlert.]

T. Davidson. (1) British Fossil Brachiopoda. Six vols. 1851–1886. (Palæont. Soc.) (2) A Monograph of Recent Brachiopoda. Trans. Linn. Soc. (Zool.), ser. 2, Vol. IV., 1886–88.

J. Hall and **J. M. Clarke.** An Introduction to the Study of the Genera of the Palæozoic Brachiopoda. (Geol. Survey New York, Palæontology. Vol. VIII.) Part I., 1892. Part II., 1894.

C. E. Beecher. (1) Development of the Brachiopoda. A. J. S., ser. 3, Vol. XLI. (1891), p. 343; XLIV. (1892), p. 133. (2) *Koninckina* etc., *ibid.* Vol. XL. (1890), p. 211. (3) Development of *Bilobites*, *ibid.* Vol. XLII. (1891), p. 51. (4) Revision of the Families of the Loop-bearing Brachiopoda. Trans. Connecticut Acad. Sci., Vol. IX. 1893.

W. King. *Lingula anatina.* A. M. N. H., ser. 4, Vol. XII. (1873), p. 1.

E. Deslongchamps. Note sur le développement du deltidium chez les Brachiopodes articulés. Bull. Soc. géol. de France, ser. 2, Vol. XIX. (1862), p. 409.

H. Friele. The Development of the Skeleton in *Waldheimia.* Arch. Math. Nat., Vol. II. (1877), p. 380.

P. Fischer and **D. P. Œhlert.** Sur l'évolution de l'appareil brachial de quelques Brachiopodes. Comptes Rendus, Vol. CXV. (1892), p. 749.

C. Schuchert. A Classification of the Brachiopoda. American Geologist, Vol. XI. (1893), p. 141; XIII. (1894), p. 80.

J. Barrande. Système Silurien du centre de la Bohême. Vol. V. 1879.

A. Bittner. Brachiopoden der Alpinen Trias. Abhandl. d. kk. geol. Reichsanstalt, Vol. XIV. 1890.

POLYZOA.

T. Hincks. History of the British Marine Polyzoa. 1880.

G. Busk. (1) Report on the Polyzoa. (Challenger Report) 1884. 1886. (2) A Monograph of the Fossil Polyzoa of the Crag. 1859. (Palæont. Soc.)

A. d'Orbigny. Paléontologie française. Terrain crétacé; Vol. V., Bryozoaires. 1850–52.

E. Pergens. Revision des Bryozoaires du Crétacé figurés par d'Orbigny. I. Cyclostomata. Ann. Soc. géol. Belg. Mém., Hydr. Vol. III. (1889), p. 305.

J. Haime. Description des Bryozoaires fossiles de la formation jurassique. Mém. Soc. géol. France, ser. 2, Vol. v. (1854) p. 156.

J. W. Gregory. (1) British Palæogene Bryozoa. Trans. Zool. Soc. Vol. xiii. (1893), p. 219. (2) Catalogue of the Fossil Bryozoa in the British Museum: Jurassic Bryozoa. 1896.

G. W. Shrubsole. (1) A Review of the British Carboniferous Fenestellidæ. Q. J. G. S., Vol. xxxv. (1879), p. 275. (2) A Review and Description of the various species of British Upper Silurian Fenestellidæ. *ibid.* Vol. xxxvi. (1880), p. 241.

G. R. Vine. Reports on Fossil Polyzoa. Rep. Brit. Assoc. 1880–92.

MOLLUSCA.

1. *General.*

S. P. Woodward. Manual of the Mollusca. Fourth edition by R. Tate. 1880.

P. Fischer. Manuel de Conchyliologie. 1887.

P. Pelseneer. Introduction à l'étude des Mollusques. 1894.

J. Sowerby. Mineral Conchology of Great Britain. 1812–29.

H. and **A. Adams.** Genera of Recent Mollusca. 3 vols. 1858.

W. Carpenter. Report on the Microscopic Structure of Shells. Rep. Brit. Assoc. for 1844 (1845), p. 24, and for 1847 (1848), p. 93.

J. Morris and **J. Lycett.** Mollusca from the Great Oolite, with supplement, 1850–63. (Palæont. Soc.)

M. Cossmann. (1) Catalogue illustré des Coquilles fossiles de l'Eocene des environs de Paris. Vols. i–v., 1886-92. (2) Essais de Paléoconchologie comparée, Vol. i. 1895.

R. B. Newton. List of the Edwards Collection of British Oligocene and Eocene Mollusca in the British Museum. 1891.

S. V. Wood. A Monograph of the Crag Mollusca. Vol. i. Univalves, 1848. Vol. ii. Bivalves 1850, and supplements. (Palæont. Soc.)

2. *Lamellibranchia.*

M. Neumayr. Beiträge zu einer morpholog. Eintheilung der Bivalven. Denkschr. der k. Akad. der Wissensch. math.-naturw. Classe (Wien). Vol. lviii. (1891), p. 701.

W. H. Dall. On the Hinge of Pelecypods. A. J. S. ser. 3, Vol. xxxviii. (1889), p. 445.

F. Bernard. Note sur le développement et la morphologie de la coquille chez les Lamellibranchs. Bull. Soc. géol. de France, ser. 3, Vol. xxiii. (1895), p. 104; xxiv. (1896), p. 54.

R. T. Jackson. Phylogeny of the Pelecypoda. The Aviculidæ and their allies. Mem. Boston Soc. Nat. Hist. Vol. IV. (1890), p. 277.

E. A. Smith. Lamellibranchiata. (Challenger Report.) 1885.

J. Barrande. Système Silurien du centre de la Bohême. Vol. VI. Acephales. 1882.

L. Beushausen. Die Lamellibranchiaten des rheinischen Devon. Abhandl. d. kk. preuss. geol. Landes-Anst. Vol. XVII. 1895.

F. Frech. Die devonischen Aviculiden Deutschlands. Abhandl. geol. Specialkarte von Preussen. Vol. IX. 1891.

W. Hind. *Carbonicola*, *Anthracomya*, and *Naiadites*. 1894. (Palæont. Soc.)

W. Amalitzky. Ueber die Anthracosien der Permformation Russlands. Palæontographica, Vol. XXXIX. (1892), p. 125.

J. Lycett. British Fossil Trigoniæ. 1872–79. (Palæont. Soc.)

A. d'Orbigny. Paléontologie française. Terr. crét. Vol. III., Lamellibranches. 1843–47.

K. A. Zittel. Die Bivalven der Gosaugebilde. Denkschr. d. k. Akad. d. Wissensch. Vol. XXIV., part ii. (1865), p. 105; XXV., part ii. (1866), p. 77.

F. Stoliczka. Cretaceous Fauna of Southern India. Vol. III., Pelecypoda (Palæontologia Indica). 1870–71.

S. V. Wood. A Monograph of Eocene Bivalves of England. 1861–71. (Palæont. Soc.)

3. *Gasteropoda* and *Scaphopoda*.

R. B. Watson. Scaphopoda and Gasteropoda. (Challenger Report.) 1886.

P. Pelseneer. Pteropoda (Challenger Report). 1888.

G. Lindström. Silurian Gasteropoda and Pteropoda of Gotland. 1884.

H. Woodward. On *Helminthochiton*. G. M. (1885), p. 352.

G. Holm. Sveriges Kambrisk-Siluriska Hyolithidæ och Conularidæ. Sveriges Geol. Undersökning. Ser. C. No. 112. Stockholm, 1893.

O. Novák. Revision der palæozoischen Hyolithiden Böhmens. Abhandl. der böhm. Gesellschaft der Wissensch. Vol. IV. 1891.

J. Donald. *Murchisonia*. Q. J. G. S. Vol. LI. (1895), p. 210; XLIII. (1887), p. 617.

E. Koken. Ueber die Entwickelung der Gastropoden vom Cambrium bis zur Trias. Neues Jahrb. für Min. etc. Beilage-Band VI. (1889), p. 305.

W. H. Hudleston. (1) British Jurassic Gasteropoda. 1887– . (Palæont.

Soc.) (2) and **E. Wilson.** Catalogue of British Jurassic Gastero poda. 1892.

E. Wilson. British Liassic Gasteropoda. G. M. (1887), pp. 193, 258.

K. A. Zittel. Die Gastropoden der Stramberger Schichten. (Palæont Mittheil.) 1873.

R. B. Newton and **G. F. Harris.** British Eocene Scaphopoda. Proc Malaco. Soc. Vol. I. (1894), p. 63.

4. *Cephalopoda.*

A. Hyatt. (1) Fossil Cephalopods in the Museum of Comparative Zoology. Embryology. Bull. Mus. Comp. Zool. Harvard. Vol. III no. 5. 1872. (2) Genesis of the Arietidæ. Smithsonian Contribu tions to Knowledge. Vol. XXVI. 1889.

L. Würtenberger. Studien über die Stammesgeschichte der Ammoniten Ein geologischer Beweis für die Darwin'sche Theorie. 1880.

W. Branco. Beiträge zur Entwickelungsgeschichte der fossilen Cepha lopoden. Palæontographica. Vol. XXVI. (1879), p. 19; XXVII. (1880), p. 17.

D. Sharpe. Mollusca in the Chalk of England. Parts I. and II. Cephalopoda. 1853–4. (Palæont. Soc.)

A. d'Orbigny. Paléontologie française. Terr. crét., Vol. I. 1840–41 Terr. jurassiques, Vol. I. 1842–49.

A. H. Foord. Catalogue of the Fossil Cephalopoda in the British Museum. Parts I. and II. 1888–91.

J. Barrande. Système Silurien du centre de la Bohême. Vol. II. (in 6 parts), Cephalopodes. 1867–70.

J. F. Blake. British Fossil Cephalopoda. Part I. 1882.

T. Wright. Monograph of the Lias Ammonites. 1878–86. (Palæont Soc.)

S. S. Buckman. A Monograph of Inferior Oolite Ammonites of the British Islands. 1887– . (Palæont. Soc.)

E. Süss. Ueber Ammoniten. Sitz. d. kk. Akad. Wissensch. Wien, Vol LII. 1865; LXI. 1870.

F. von Quenstedt. Die Ammoniten des schwabischen Jura. Vols. I—III. 1883–88.

R. B. Newton and **G. F. Harris.** British Eocene Cephalopoda. Proc Malaco. Soc. Vol. I. (1894), p. 119.

M. Neumayr. I. Jura Studien. Ueber Phylloceraten. Jahrb. d. kk geol. Reichsanstalt. Vol. XXI. (1871), p. 297.

K. A. Zittel. Die Cephalopoden der Stramberger Schichten. (Palæont Mittheilungen.) 1868.

E. Mojsisovics von Mojsvár. Die Cephalopoden der mediterranen Triasprovinz. Abhandl. d. kk. geol. Reichsanstalt, Vol. x. 1882.

C. Schlüter. Cephalopoden der oberen deutschen Kreide. Palæontographica, Vols. xxi., xxiv., 1871–76.

M. Neumayr and **V. Uhlig.** Ueber Ammonitiden aus den Hilsbildungen Norddeutschlands. Palæontographica, Vol. xxvii. (1881), p. 135.

A. de Grossouvre. Les Ammonites de la Craie supérieure. (Mém. explicat. Carte géol. de la France.) 1893.

T. H. Huxley. On the structure of the Belemnitidæ. (Mem. Geol. Survey.) 1864.

J. Phillips. A Monograph of the British Belemnitidæ. 1865. (Palæont. Soc.)

ARTHROPODA.

1. *Crustacea.*

H. Woodward. (1) Catalogue of British Fossil Crustacea. 1877. (2) On fossil Crustacea. Addresses to Geol. Soc. Q. J. G. S. Vols. li., lii. 1895–96.

H. Milne Edwards. Histoire naturelle des Crustacées, 1834–40.

A. Vogdes. Bibliography of Palæozoic Crustacea 1698–1889. Bull. U. S. Geol. Survey 1890. Second edition, 1893.

T. R. Jones. (1) A Monograph of the Fossil Estheriæ. 1862. (2) A Monograph of the Tertiary Entomostraca of England. 1856. (Palæont. Soc.) Supplement 1889.

T. R. Jones, J. W. Kirkby and **G. S. Brady.** A Monograph of the British Fossil Bivalved Entomostraca from the Carboniferous Formations. 1874–84. (Palæont. Soc.)

T. R. Jones. A Monograph of the Entomostraca of the Cretaceous Formations of England. 1849. (Palæont. Soc.) Supplement 1890.

C. Darwin. (1) A Monograph on the Fossil Lepadidæ. 1851. (Palæont. Soc.) (2) A Monograph on the Fossil Balanidæ. 1854. (Palæont. Soc.)

T. R. Jones and **H. Woodward.** A Monograph of the British Palæozoic Phyllocarida. 1888–92. (Palæont. Soc.)

A. S. Packard. A Monograph of the N. American Phyllopod Crustacea. (Geol. Survey of the Territories 12th Ann. Rep.) 1883.

G. O. Sars. Report on the Phyllocarida (Leptostraca). (Challenger Report.) 1887.

J. W. Salter. A Monograph of the British Trilobites from the Cam-

brian, Silurian, and Devonian Formations. 1864–1883. (Palæont. Soc.)

H. Woodward. A Monograph of the British Carboniferous Trilobites. 1883–4. (Palæont. Soc.)

J. Barrande. Système Silurien du centre de la Bohême. Trilobites. 1852.

C. Lapworth. On *Olenellus callavei* and its geological relationships. G. M. dec. 3, Vol. VIII. (1891), p. 529, plates xiv. and xv.

C. D. Walcott. The Fauna of the Lower Cambrian or Olenellus zone. (Ann. Rep. U. S. Geol. Survey.) 1890.

B. N. Peach. Olenellus-Zone in N. W. Highlands. Q. J. G. S. Vol. XLVIII. (1892), p. 227; L. (1894), p. 661.

J. Hall and **J. M. Clarke.** Trilobites and other Crustacea. (Geol. Survey of New York. Palæontology. Vol. VII.) 1888.

C. D. Walcott. The Trilobite: New and Old Evidence relating to its Organization. (Bull. Mus. Comp. Zool., Vol. VIII.), 1881.

W. D. Matthew. Antennæ etc. of *Triarthrus*. A. J. S. Vol. XLVI. Aug. 1893, p. 121.

C. E. Beecher. (1) Papers on *Triarthrus* (appendages etc.) A. J. S. Vol. XLVI. (1893), pp. 361, 467. A. J. S. Vol. XLVII. (1894), p. 298. American Geologist, Vol. XIII. (1894), p. 38. *Ibid.* Vol. XV. (1895), p. 91. A. J. S. ser. 4, Vol. I. (1896), p. 251. G. M. dec. 4, Vol. III. (1896), p. 193. (2) On *Trinucleus*. A. J. S. Vol. XLIX. (1895), p. 307. (3) Larval Stages of Trilobites. American Geologist, Vol. XVI. (1895), p. 166.

H. M. Bernard. Systematic Position of the Trilobites. Q. J. G. S. Vol. L. (1894), p. 411; Vol. LI. (1895), p. 352.

T. Bell. A Monograph of the Fossil Malacostracous Crustacea. 1857–62. (Palæont. Soc.)

J. Carter. On the Decapod Crustacea of the Oxford Clay. Q. J. G. S., Vol. XLII. (1886), p. 542.

B. N. Peach. On some new Crustaceans from the Lower Carboniferous Rocks of Eskdale and Liddesdale. Trans. Roy. Soc. Edin., Vol. XXX. (1880-83), pp. 73, 511.

L. von Ammon. Ein Beitrag zur Kenntniss der fossilen Asseln. Sitz. d. kk. Akad. d. Wissensch. math.-phys. Classe. Heft IV. 1882. p. 507.

A. Oppel. Ueber jurassische Crustaceen. (Palæont. Mittheil. aus dem Museum des kgl. bayer. Staates.) 1862.

J. W. Salter. Higher Crustacea from the Coal Measures. Q. J. G. S. Vol. XVII. (1861), p. 528.

T. R. R. Stebbing. Amphipoda. (Challenger Report.) 1888.

F. E. Beddard. Isopoda. (Challenger Report.) 1884. 1886.
C. S. Bate. Crustacea Macroura. (Challenger Report.) 1888.
E. J. Miers. Brachyura. (Challenger Report.) 1886.

2. *Myriapoda.*

B. N. Peach. Myriapods from the Lower Old Red Sandstone of Forfarshire. Proc. Roy. Phys. Soc. Edin. Vol. VII. (1882), p. 177.
S. H. Scudder. (1) Archipolypoda, a type of Myriapods from the Carboniferous. Mem. Boston Soc. Nat. Hist. Vol. III. (1882), p. 143. (2) Two new types of Carboniferous Myriapods. *Ibid.* Vol. III. (1884), p. 285.

3. *Insecta.*

S. H. Scudder. (1) Index to the Fossil Insects of the World, including Myriapods and Arachnids. Bull. U. S. Geol. Survey, 1891. (2) Bibliography of Fossil Insects, *Ibid.* 1890. (3) Palæodictyoptera. Mem. Boston Soc. Nat. Hist. Vol. III. (1885), p. 319.
P. B. Brodie. A history of Fossil Insects in the Secondary rocks of England. 1845.
C. Brongniart. Recherches pour servir à l'histoire des Insectes fossiles des Temps Primaires. Bull. Soc. Industr. Min. St Etienne. Ser. 3. Vol. VII. 1893.

4. *Arachnida.*

T. H. Huxley and **J. W. Salter.** On Pterygotus. (Mem. Geol. Survey, Organic Remains.) 1859.
H. Woodward. (1) On some points in the Structure of the Xiphosura. Q. J. G. S. Vol. XXIII. (1867), p. 28; XXVIII. (1872), p. 46. (2) A Monograph of the British Fossil Crustacea belonging to the order Merostomata. 1866–78. (Palæont. Soc.)
M. Laurie. Anatomy and Relations of the Eurypteridæ. Trans. Roy. Soc. Edinburgh, Vol. XXXVII. (1893), p. 509.
F. Schmidt. Die Crustaceenfauna der Eurypterusschichten von Rootziküll auf Oesel. Mém. de l'Acad. impér. de St Pétersbourg, ser. 7, Vol. XXXI. (1883), p. 28.
B. N. Peach. Fossil Scorpions from the Carboniferous Rocks of Scotland and the English Borders. Trans. Roy. Soc. Edin. Vol. XXX. (1881), p. 397.

INDEX.

Names of genera are printed in italics.

Acanthoceras, 219
Acarina, 271
Acaste, 243
Acephala, 152
Acervularia, 65
Acidaspis, 244
Acridiidæ, 261
Acrosalenia, 93
Actinaria, 60
Actinoceras, 207
Actinocrinus, 103
Actinostroma, 57
Actinozoa, 58
Ad-ambulacral plates, 78
Adductors, 119, 154
Æglina, 242
Ægoceras, 216
Agnostus, 238
Alcyonaria, 69
Alectryonia, 166
Amaltheus, 214
Ambulacral area, 87
,, groove, 78
,, ossicle, 78, 83
,, plate, 87
Ammonites, 213
Ammonoidea, 209
Amphipoda, 258
Amplexus, 67
Ampyx, 238
Anal siphon, 151
Ananchytes, 95
Anarcestes, 212
Ancyloceras, 219
Angelina, 240
Angle of divergence, 46
Anomia, 163
Antennæ, 228
Anthracomarti, 271
Anthracomya, 172
Anthracosia, 172
Anthrapalæmon, 257
Antipatharia, 60
Apex (Gasteropoda), 180
Aphididæ, 262
Apical disc, 85
Apiocrinus, 105
Aporosa, 63
Aporrhais, 190
Aptera, 261
Aptychus, 210
Apygia, 125
Arachnida, 263
Araneida, 271

Arca, 161
Arcestes, 214
Archæocidaris, 91
Archæoniscus, 258
Archæoscyphia, 33
Archidesmus, 260
Architarbus, 271
Arcomya, 176
Arctica, 172
Area, 118, 156
Arenaceous Foraminifera, 15
Areola, 89
Argonauta, 220, 221
Arietites, 216
Arms (Brachiopoda), 116, 121
Artemis, 174
Arthropleura, 259
Arthropoda, 226
Arthropomata, 125
Arthrostraca, 257
Articulata, 128
Asaphus, 241
Ascoceras, 208
Asiphonida, 160
Astarte, 171
Asteractinella, 37
Asteroidea, 77
Astræospongia, 37
Astropecten, 81
Astylospongia, 33
Atremata, 125
Atrypa, 133
Aturia, 209
Auricles (Echinoidea), 90
Auriform gasteropods, 184
Autopores, 71
Autozooids, 69
Avellana, 194
Avicula, 165
Avicularia, 144
Aviculopecten, 166
Axal furrow, 231
Axinæa, 162

Baculites, 216
Bairdia, 249
Balanus, 250
Basal budding, 62
,, plates, 102, 109
Belemnitella, 223
Belemnites, 221
Belemnoidea, 220
Belinurus, 265
Bellerophon, 186
Belosepia, 221
Beyrichia, 248
Bigeminal, 87
Blastoidea, 109
Blattidæ, 261
Boss, 88
Bothriocidaris, 90
Brachial plates, 102
,, skeleton, 121
Brachiopoda, 115
Brachyura, 256
Branchial siphon, 151
Branchiata, 227
Bronteus, 242
Bryograptus, 55
Bryozoa, 142
Buccal plate, 83
Buccinum, 191
Bulla, 194
Bunodes, 265
Byssus, 151, 159

Calcarea, 38
Calceola, 68
Calcispongiæ, 38
Calicular budding, 62
Callus, 182
Calymene, 240
Calyptræa, 188
Calyx (corals), 61

Calyx (crinoids), 102
,, (cystideans), 107
,, (blastoids), 109
Carapace, 228, 247
Carbonicola, 172
Cardinal process, 120
Cardinia, 172
Cardiola, 162
Cardita, 170
Cardium, 169
Carina, 250
Caryocaris, 252
Central disc, 45
Centro-dorsal plate, 101, 105
Cephalic shield, 230
Cephalopoda, 201
Cephalothoracic shield, 228, 253
Cephalothorax, 228, 264, 267
Ceratiocaris, 251
Ceratites, 213
Ceratospongiæ, 31
Cerithium, 190
Ceromya, 176
Cervical suture, 253
Chætopoda, 113
Chama, 168
Chasmops, 243
Cheeks (Trilobita), 230
Cheilostomata, 146
Cheirurus, 243
Chelæ, 254
Cheliceræ, 263, 265
Chenopus, 190
Chilopoda, 259
Chirodota, 99
Chonetes, 130
Cicadidæ, 262
Cidaris, 92
Cirri, 101
Cirripedia, 249
Cirrus, 187
Clathrodictyon, 58
Climacograptus, 55
Clisiophyllum, 67
Clistenterata, 125
Clymenia, 211
Cœlentera, 41
Cœlenteron, 42
Cœnenchyma, 63
Cœnograptus, 53
Cœnosarc, 43
Coleoptera, 262
Collyrites, 95
Columella (Corals), 61
,, (Gasteropoda), 181
Common canal, 45
Communication-plates, 145
Conical gasteropods, 183
Conjugate pores, 88
Conocardium, 170
Conocephalites, 240
Conocoryphe, 240
Conularia, 195
Conus, 193
Convolute gasteropods, 184
Copepoda, 229
Corallite, 60
Corallum, 60
Corbicula, 173
Corbula, 175
Corona, 85
Cosmoceras, 218
Costæ, 62
Crania, 127
Crassatella, 171
Craticularia, 36
Crinoidea, 100
Crioceras, 219
Crotalocrinus, 104
Crustacea, 228
Ctenodonta, 161
Cucullæa, 162
Cumacea, 252
Cyathocrinus, 103

Cyathophyllum, 65
Cyclosphæroma, 259
Cyclostomata, 145
Cylindrical gasteropods, 184
Cyphosoma, 93
Cypræa, 191
Cypridea, 248
Cyprina, 172
Cypris, 248
Cyrena, 173
Cyrtia, 133
Cyrtoceras, 208
Cyrtograptus, 53
Cystidea, 107
Cystiphyllum, 67
Cythere, 249
Cytherea, 174

Dactylioceras, 217
Dalmanites, 243
Decapoda (Cephalopoda), 221
Decapoda (Crustacea), 253
Deltidium, 119
Deltoid plates, 110
Dendrograptus, 43
Dendroid corals, 63
Dental plates, 117
Dentalium, 201
Dextral gasteropods, 181
Diadema, 93
Dibranchiata, 220
Dicellograptus, 54
Dichograptus, 54
Dicranograptus, 54
Dictyonema, 43
Dictyophyton, 35
Dicyclic, 102
Didymograptus, 54
Dimyaria, 152, 160
Diplograptus, 54
Diplopoda, 259
Diprionidian, 46
Diptera, 263
Disc (Asteroidea), 77
,, (Ophiuroidea), 83
Discina, 127
Discinisca, 127
Discites, 208
Discoidal gasteropods, 183
Discoidea, 94
Dissepiments, 62
Dithyrocaris, 252
Divaricator muscles, 119
Dorso-central plate, 87, 105
Doryderma, 34
Dosinia, 174

Ecardines, 125
Echinobrissus, 95
Echinocaris, 252
Echinoconus, 94
Echinocorys, 95
Echinocystites, 91
Echinoderma, 75
Echinoidea, 84
Echinosphærites, 108
Echinozoa, 77
Echinus, 85
Ectoderm, 28
Ectoprocta, 145
Elasmostoma, 38
Elongate gasteropods, 183
Emarginula, 185
Encrinasteriæ, 80
Encrinurus, 243
Encrinus, 104
Endoderm, 28
Endothyra, 18
Entomis, 248
Entomostraca, 229
Eocidaris, 97
Eoscorpius, 270
Eosphæroma, 259
Eozoön, 22

Ephemeridæ, 262
Epitheca, 61
Eryma, 255
Eryon, 255
Escutcheon, 154
Estheria, 230
Euasteriæ, 80
Euechinoidea, 91
Euomphalus, 186
Euphoberia, 260
Eurypterida, 266
Eurypterus, 268
Excurrent canals, 27
Exogyra, 167
Exsert septa, 61

Facial suture, 232
Fasciole, 89
Fasciculatia, 146
Favosites, 70
Fenestella, 146
Fission in corals, 62
Fissurella, 185
Fistulipora, 69
Flesh-spicules, 29
Foot (Mollusca), 148
,, (Lamellibranchia), 149
,, (Gasteropoda), 179
,, (Scaphopoda), 201
,, (Cephalopoda), 202
Foramen, 119
Foraminifera, 14
Forficulidæ, 261
Fossula, 61
Funnel, 202
Fusiform gasteropods, 184
Fusulina, 20
Fusus, 192

Galerites, 94
Gammarus, 258
Gasteropoda, 179
Genital plates, 85
Geodites, 33
Gervillia, 164
Glabella, 230
Globigerina, 19
Globular gasteropods, 184
Glycimeris, 176
Glyphea, 255
Glyphioceras, 212
Glyptocrinus, 106
Glyptosphærites, 107
Gomphoceras, 207
Gonangia, 49
Goniaster, 81
Goniatites, 212
Goniomya, 176
Goniophyllum, 68
Granatocrinus, 112
Graptolitoidea, 43
Griffithides, 245
Gryllidæ, 261
Gryphæa, 166
Guard of *Belemnites*, 221
Gymnolæma, 145
Gymnomyxa, 14

Halysites, 71
Hamites, 215
Harpoceras, 217
Head-shield, 230
Heliolites, 71
Helix, 196
Hemiaspis, 265
Hemicidaris, 93
Hemiptera, 262
Heteractinellidæ, 37
Heteromyaria, 160
Heteropoda, 193
Hexactinellidæ, 35
Hinge (Brachiopoda), 117
,, (Lamellibranchia), 155
Hinge-line (Brachiopoda), 117

Hinge-line (Lamellibranchia), 155
Hinnites, 167
Hippopodium, 171
Hippurites, 169
Holaster, 96
Holectypus, 94
Holmia, 240
Holocystis, 65
Holostomatous, 182
Holothuroidea, 99
Homalonotus, 241
Hoplites, 219
Hoploparia, 256
Hyalostelia, 35
Hydractinia, 43
Hydromedusæ, 42
Hydrospire, 111
Hydrotheca, 45, 46
Hydrozoa, 42
Hymenocaris, 251
Hymenoptera, 263
Hyolithes, 195
Hypostome, 233

Illænus, 242
Imperforate gasteropods, 182
Inarticulata, 125
Incurrent canals, 27
Inflected lip, 183
Infra-basal plates, 102
Ink-sac, 203, 220
Inner lip of gasteropods, 182
Inoceramus, 164
Insecta, 260
Integripalliata, 160
Inter-ambulacral area, 87
,, ,, plates, 87
Inter-brachial area, 83
,, ,, plates, 103
Inter-radial plates, 102
Isastræa, 64
Ischadites, 35
Isocardia, 173
Isopoda, 258

Kampecaris, 260
Keel (Ammonoidea), 211

Labechia, 58
Lagena, 19
Lamellibranchia, 149
Lancet-plate, 110
Lateral budding of corals, 62
Leda, 161
Lepadocrinus, 108
Lepas, 250
Leperditia, 247
Lepidoptera, 262
Leptæna, 130
Leptograptus, 53
Leptostraca, 251
Libellulidæ, 262
Ligament, 156
Lima, 167
Limnæa, 196
Limulus, 264, 265
Lingula, 126
Lingulella, 126
Litharæa, 68
Lithistidæ, 33
Lithodomus, 164
Lithostrotion, 66
Littorina, 188
Lituola, 18
Lobes (Ammonoidea), 210
Locustidæ, 261
Longitudinal ornament of gasteropods, 184
Lonsdaleia, 67
Lophophore, 142
Lucina, 173
Lunule, 154
Lyopomata, 125
Lytoceras, 215

Macrocephalites, 217
Macroscaphites, 215
Macrura, 254
Mactra, 174
Madreporaria, 60
Madreporic plate, 78, 86
Magellania, 137
Malacostraca, 250
Mamelon, 88
Mandibles, 228
Mantle (Brachiopoda), 115
,, (Lamellibranchia), 149
,, (Gasteropoda), 179
,, (Scaphopoda), 201
,, (Cephalopoda), 202
Mantle-cavity, 115, 149
Marginal plates, 78
Marsupites, 105
Massive corals, 63
Maxillæ, 228
Maxillipedes, 254
Melania, 189
Membranipora, 146
Meretrix, 174
Merostomata, 264
Mesenteries, 42, 58
Mesoderm, 28
Mesonacis, 240
Metastoma, 268, 233
Metopaster, 80
Meyeria, 255
Michelinia, 70
Micraster, 96
Microdiscus, 238
Miliola, 18
Mitra, 192
Modiola, 164
Mollusca, 148
Monactinellidæ, 31
Monocyclic, 102
Monograptus, 53
Monomyaria, 152, 160
Monoprionidian, 46
Monticulipora, 69
Monticuliporoidea, 69
Montlivaltia, 64
Multilocular Foraminifera, 15
Murchisonia, 186
Murex, 192
Mya, 175
Myacites, 176
Myriapoda, 259
Mytilus, 163
Myxospongiæ, 31

Nassa, 192
Natica, 188
Nauplius larva, 229, 250
Nautiloidea, 204
Nautilus, 208
Necrogammarus, 258
Necroscylla, 253
Nematocysts, 41
Neolimulus, 265
Neotremata, 126
Nerinea, 190
Nerita, 187
Neuroptera, 262
Nodosaria, 19
Non-Calcarea (Porifera), 31
Notonectidæ, 263
Nucleolites, 95
Nucula, 161
Nummulites, 20

Ocelli, 264
Octactinellidæ, 37
Octopoda, 223
Octopus, 223
Ocular plates, 85
Odontochile, 243
Odontophore, 180, 203
Ogygia, 241
Olenelloides, 240

Olenellus, 239
Olenus, 238
Omphyma, 66
Oœcium, 144
Operculum, 183
Ophiuroidea, 81
Opilionina, 271
Opis, 171
Opisthobranchia, 194
Oral plates, 100
Orbiculoidea, 127
Orthis, 131
Orthoceras, 206
Orthoptera, 261
Osculum, 28
Ostia, 28
Ostracoda, 247
Ostrea, 166
Outer lip (Gasteropoda), 182
Oxynoticeras, 213

Pachinion, 34
Pachypora, 70
Palæaster, 80
Palæechinoidea, 90
Palæechinus, 90
Palæga, 259
Palæoblattina, 260, 261
Palæocorystes, 256
Palæopalæmon, 257
Palæophonus, 270
Pali, 62
Pallial line, 154
,, sinus, 155
Paludina, 188
Panopea, 176
Paradoxides, 239
Parapodia, 113
Parasmilia, 64
Parkinsonia, 218
Patella, 185
Paterina, 125
Pearly layer, 157
Pecten, 167
Pectunculus, 162
Pedicellariæ, 78
Pedipalpi, 271
Peduncle, 118
Pelecypoda, 149
Pelmatozoa, 77
Peltastes, 92
Peltoceras, 218
Pentamerus, 136
Pentremites, 109–111
Perforata, 63
Perforate gasteropods, 182
Periderm, 45
Peripatus, 227
Peripetalous fasciole, 89
Periproct, 85
Perisphinctes, 218
Peristome, 90, 182
Perna, 165
Peronella, 38
Peronidella, 38
Petaloid ambulacra, 88
Phacops, 243
Phalangida, 271
Phasianella, 187
Phillipsia, 245
Pholadomya, 177
Pholas, 177
Phormosella, 35
Phragmoceras, 207
Phragmocone, 222
Phryganidæ, 262
Phylactolæma, 145
Phyllocarida, 251
Phylloceras, 214
Phyllograptus, 55
Phyllopoda, 229
Pinna, 164
Pinnules, 100
Planorbis, 196

Platycrinus, 104
Pleura, 233
Pleurodictyum, 70
Pleuromya, 176
Pleuropygia, 125
Pleurotoma, 193
Pleurotomaria, 186
Plicatula, 168
Plocoscyphia, 37
Plumulites, 250
Pollicipes, 250
Polychæta, 113
Polypary, 45
Polypide, 143
Polyplacophora, 185
Polyzoa, 142
Porcellanous Foraminifera, 14
Pore-rhombs, 108
Porifera, 27
Posidonomya, 166
Prearcturus, 259
Prestwichia, 265
Primitia, 247
Prismatic layer, 157
Productus, 129
Prolecanites, 213
Pro-ostracum, 223
Proscorpius, 270
Prosobranchia, 185
Protaster, 84
Protegulum, 124
Protocardia, 170
Protoconch, 206, 210
Protocystites, 108
Protospongia, 35
Prototracheata, 227
Protozoa, 13
Protremata, 128
Pseudocrinites, 108
Pseudodeltidium, 119
Pseudodiadema, 93
Pseudomelania, 189
Pseudomonotis, 165
Pseudopodia, 13
Pseudoscorpionida, 270
Psiloceras, 216
Pterinea, 165
Pteropoda, 194
Pterygotus, 269
Pulmonāta, 195
Purpura, 192
Pygaster, 95
Pygidium, 233

Radial plates, 84, 102, 109
Radiolaria, 24
Rastrites, 53
Receptaculites, 35
Reflected lip (Gasteropoda), 182
Reniera, 31
Retiolites, 55
Rhizophyllum, 68
Rhizopoda, 14
Rhynchonella, 134
Rostellaria, 191
Rostrum, 254
Rotalia, 20
Rugosa, 63

Saccamina, 18
Saddles (Ammonoidea), 210
Salenia, 92
Saxicava, 176
Scala, 189
Scalaria, 189
Scalpellum, 250
Scaphites, 219
Scaphopoda, 201
Schizodus, 163
Schizopoda, 253
Schlœnbachia, 219
Scorpionida, 270
Scutum, 250
Scyphomedusæ, 43

Sea-cucumbers, 99
Sea-lilies, 100
Sea-urchins, 84
Sepia, 221
Septa (Foraminifera), 15
,, (Corals), 61
,, (Cephalopoda), 205
Septal fossula, 61
,, necks, 205
Serpula, 114
Sicula, 45, 48, 49
Simple ambulacra, 88
Sinistral gasteropods, 181
Sinupalliata, 160
Siphonia, 34
Siphonida, 160
Siphonopores, 71
Siphonostomatous, 182
Siphonozooids, 69
Siphons, 151, 179
Siphuncle, 205
Skeletal-spicules, 29
Slimonia, 270
Solarium, 188
Solen, 175
Sphærospongia, 35
Spicules, 29
Spines (Echinoidea), 89
Spiracles, 110
Spiral angle, 181
,, ornament, 184
Spire of gasteropods, 180
Spirifer, 132
Spiriferina, 133
Spirorbis, 114
Spirula, 220, 221
Spondylus, 167
Sponges, 27
Spongilla, 31
Spongin, 29
Squilla, 253
Starfishes, 77
Stem (Crinoidea), 101
Stephanoceras, 217
Stomatopoda, 253
Stone-canal, 80
Stricklandia, 135
Stringocephalus, 137
Stromatopora, 57
Stromatoporoidea, 57
Strombus, 191
Strophomena, 131
Stylonurus, 269
Sub-anal fasciole, 89
Sub-petaloid ambulacra, 88
Supplemental skeleton, 16
Sur-anal plate, 87
Suture (Gasteropoda), 180
,, (Cephalopoda), 206, 210
Synapta, 99
Synapticula, 62
Syringopora, 70

Tabula, 62
Tabulata, 64
Tellina, 174
Telotremata, 132
Telson, 255, 268
Tentaculites, 195
Terebratula, 136
Terebratulina, 137
Teredo, 177
Tergum, 250
Termitidæ, 262
Testicardines, 125
Tetrabranchiata, 204
Tetracidaris, 97
Tetractinellidæ, 33
Tetragraptus, 54
Textularia, 19
Thamnastræa, 64
Theca, 195
Theca (Corals), 61
Thecosmilia, 65

Tholiasterella, 37
Thoracostraca, 252
Thracia, 177
Tiarechinus, 97
Tracheata, 227
Trachyceras, 213
Transverse ornament, 184
Tretenterata, 125
Triarthrus, 235
Trigeminal, 87
Trigonia, 162
Trilobita, 230
Trimerocephalus, 243
Trinucleus, 238
Trochiform gasteropods, 183
Trochus, 187
Tube-feet, 77, 79, 82
Tubercles, 88
Tubipora, 69
Turbinate gasteropods, 183
Turbo, 186
Turreted gasteropods, 183
Turrilepas, 250
Turrilites, 216
Turritella, 189

Umbilicus, 182, 211
Umbo, 117, 153
Uncites, 133
Unigeminal, 87
Unilocular, 15
Unio, 172
Univalve, 180

Varices, 184
Venericardia, 170
Ventriculites, 36
Venus, 174
Verruculina, 33
Vesicular tissue, 62
Vibracula, 144
Visceral chamber, 61
Vitreous Foraminifera, 14
Viviparus, 188
Voluta, 193

Waldheimia, 137
Water-vascular system, 75, 79, 82 101
Whorl, 180
Worms, 113

Xanthopsis, 250
Xiphosura, 264
Xylobius, 260

Zaphrentis, 67
Zoœa, 229, 250
Zoantharia, 59
Zoarium, 142
Zoœcium, 142

CAMBRIDGE: PRINTED BY J. AND C. F. CLAY, AT THE UNIVERSITY PRESS.

Cambridge Natural Science Manuals.

BIOLOGICAL SERIES.

General Editor, A. E. Shipley, M.A.,
Fellow and Tutor of Christ's College.

Now Ready.

Elementary Palæontology—Invertebrate	H. Woods, M.A., F.G.S. 2nd Ed.	6*s*.
Elements of Botany	F. Darwin, M.A., F.R.S. ,,	6*s*.
Practical Physiology of Plants	F. Darwin, & E. H. Acton, M.A.	6*s*.
Practical Morbid Anatomy	H. D. Rolleston, M.D., F.R.C.P. & A. A. Kanthack, M.D., M.R.C.P.	6*s*.
Zoogeography	F. E. Beddard, M.A., F.R.S.	6*s*.
Petrology for Students	A. Harker, M.A., F.G.S.	7*s*. 6*d*.

In Preparation.

Fossil Plants	A. C. Seward, M.A., F.G.S.
The Vertebrate Skeleton	S. H. Reynolds, M.A. [*In the Press.*
Flowering-Plants and Ferns, in two vols.	J. C. Willis, M.A. [*Nearly Ready.*

PHYSICAL SERIES.

General Editor, R. T. Glazebrook, M.A. F.R.S.,
Fellow of Trinity College, Cambridge, Assistant Director of the Cavendish Laboratory.

Now Ready.

Heat and Light	R. T. Glazebrook, M.A., F.R.S.	5*s*.
,, ,, in two separate parts	,, ,,	*each* 3*s*.
Mechanics and Hydrostatics	,, ,,	8*s*. 6*d*.
,, ,, in three separate parts		
Part I. **Dynamics**	,, ,,	4*s*.
,, II. **Statics**	,, ,,	3*s*.
,, III. **Hydrostatics**	,, ,,	3*s*.
Solution and Electrolysis	W. C. D. Whetham, M.A.	7*s*. 6*d*.

In Preparation.

Electricity and Magnetism	R. T. Glazebrook, M.A., F.R.S.
Sound	J. W. Capstick, M.A.

Now Ready.

Laboratory Note-Books of Elementary Physics	L. R. Wilberforce, M.A., and T. C. Fitzpatrick, M.A.

I. **Mechanics and Hydrostatics.** II. **Heat and Optics.**
III. **Electricity and Magnetism.** *each* 1*s*.

Other volumes are in preparation and will be announced shortly.

7/10/96

BIOLOGICAL SERIES.

Elementary Palæontology—Invertebrate. By Henry Woods, M.A., F.G.S. With Illustrations. Crown 8vo Second Edition. 6*s.*

Nature. As an introduction to the study of palæontology Mr Woods's book is worthy of high praise.

Elements of Botany. By F. Darwin, M.A., F.R.S. Second Edition. Crown 8vo. With numerous Illustrations. 6*s.*

Journal of Education. We are very pleased with this little book, which teaches without being didactic; and leads us into the various phenomena o plant life with an easy gait, quite free from the halting jolt of the averag text-book on vegetable morphology and physiology. The style is pointed indeed almost abrupt; but still very clear and concise. The description o the various examples of physiological functions amongst plants is distinctly good, and Mr Darwin's method of teaching the most fundamental function of plant life from simple experiments with easily get-at-able specimens i thoroughly scientific. It is a noteworthy addition to our botanical literature

Practical Physiology of Plants. By F. Darwin, M.A. F.R.S., Fellow of Christ's College, Cambridge, and Reade in Botany in the University, and E. H. Acton, M.A., lat Fellow and Lecturer of St John's College, Cambridge. Wit Illustrations. Second Edition. Crown 8vo. 6*s.*

Nature. A volume of this kind was very much needed, and it is matter for congratulation that the work has fallen into the most competen hands. There was nothing of the kind in English before, and the book wil be of the greatest service to both teachers and students..... The thoroughl practical character of Messrs Darwin and Acton's book seems to us a grea merit; every word in it is of direct use to the experimental worker and t him alone.....The authors are much to be congratulated on their work which fills a serious gap in the botanical literature of this country.

Zoogeography. By F. E. Beddard, M.A., F.R.S. Wit Maps. 6*s.*

Daily Chronicle. Although included in the series of Cambridge Natur Science Manuals, and therefore designed chiefly for students of biology Mr Beddard deals with his subject in a clear and graphic way that shoul commend his book to the general reader interested in the question. H style, while never lacking dignity, avoids the dulness which too ofte accompanies that virtue.

Press Opinions.

BIOLOGICAL SERIES.

Practical Morbid Anatomy. By H. D. Rolleston, M.D., F.R.C.P., Fellow of St John's College, Cambridge, Assistant Physician and Lecturer on Pathology, St George's Hospital, London, and A. A. Kanthack, M.D., M.R.C.P., Lecturer on Pathology, St Bartholomew's Hospital, London. Crown 8vo. 6*s.*

British Medical Journal. The editor of the "Cambridge Natural Science Manuals" has been fortunate not only in the selection of the above-named subject but also in securing as authors Drs Rolleston and Kanthack..... This manual can in every sense be most highly recommended, and it should supply what has hitherto been a real want.

Lancet. This small and beautifully printed volume is one of the biological series of the Cambridge Natural Science Manuals, and is intended to serve as a handbook to the post-mortem room, and it does so most completely.....If post-mortem examinations were carried out in the thorough and orderly manner laid down in this handbook this experience would be of the utmost service to the student in his after career, whether as a practitioner or teacher.

PHYSICAL SERIES.

Heat and Light. An Elementary Text-book, Theoretical and Practical, for Colleges and Schools. By R. T. Glazebrook, M.A., F.R.S., Assistant Director of the Cavendish Laboratory, Fellow of Trinity College, Cambridge. Crown 8vo. 5*s.* The two parts are also published separately.

Heat. 3*s.* Light. 3*s.*

Nature. Teachers who require a book on Light, suitable for the Class-room and Laboratory, would do well to adopt Mr Glazebrook's work.

Journal of Education. We have no hesitation in recommending this book to the notice of teachers.

School Guardian. It is no undue praise to say that they are worthy both of their author and of the house by which they are issued.

Teachers' Aid. Text-books of which it would be almost impossible to speak too highly.

Petrology for Students. An Introduction to the Study of Rocks under the Microscope. By A. Harker, M.A., F.G.S., Fellow of St John's College, and Demonstrator in Geology (Petrology) in the University of Cambridge. Crown 8vo. 7*s.* 6*d.*

Nature. There can be nothing but praise for the clear and straightforward way in which the author has presented his facts, and for the wealth of new matter which the book contains. The book shows evidence of most careful research into the literature of the subject, and is in fact thoroughly up to date, containing many extracts from papers which have appeared within the present year.

Athenæum. All working Students will welcome Mr Harker's manual with gratitude.

Press Opinions.

PHYSICAL SERIES.

Mechanics and Hydrostatics. An Elementary Text-book Theoretical and Practical, for Colleges and Schools. By R. T. GLAZEBROOK, M.A., F.R.S., Fellow of Trinity College Cambridge, Assistant Director of the Cavendish Laboratory With Illustrations. Crown 8vo. 8*s.* 6*d.*

Also in separate parts.

Part I. **Dynamics.** 4*s.* Part II. **Statics.** 3*s.*
Part III. **Hydrostatics.** 3*s.*

Educational Times. Mr Glazebrook's excellent elementary text-boo combines the theoretical and the practical more successfully than an school-book which we have seen. Its statements are at once plain an sound and many of his directions for experimentation are remarkably ap and striking. We are glad to note that the author has undertaken t prepare further volumes in the Physical Series of the 'Cambridge Natura Science Manuals,' which promises to make a new departure in elementar science manuals for school and college.

Educational News (Edinburgh). This forms one of the very excellen Physical Series of the 'Cambridge Natural Science Manuals.' Written b a practical teacher, it shows throughout a thorough grasp of the subject and is treated in a masterly and capable manner. To students who desire reliable manual on this subject—both theoretical and practical—we would thoroughly recommend the book before us. There can be no doubt tha experiments in science must be performed by the learners if they are to b of any value, and the author of this manual, recognizing the value an importance of such methods, has made this an important feature of th book. He has shown in a clear, concise, and careful way the theory o the experiments and the results which may be deduced from them. Th book is an admirable one, and very well adapted to the needs of students o this branch of physical science.

Journal of Education. A very good book, which combines the theoretica and practical treatment of Mechanics very happily.

Solution and Electrolysis. By W. C. D. WHETHAM, M.A Fellow of Trinity College. Crown 8vo. 7*s.* 6*d.*

Electrician. This book is a valuable addition to the literature of th subject.

London: C. J. CLAY AND SONS,
CAMBRIDGE UNIVERSITY PRESS WAREHOUSE,
AVE MARIA LANE.

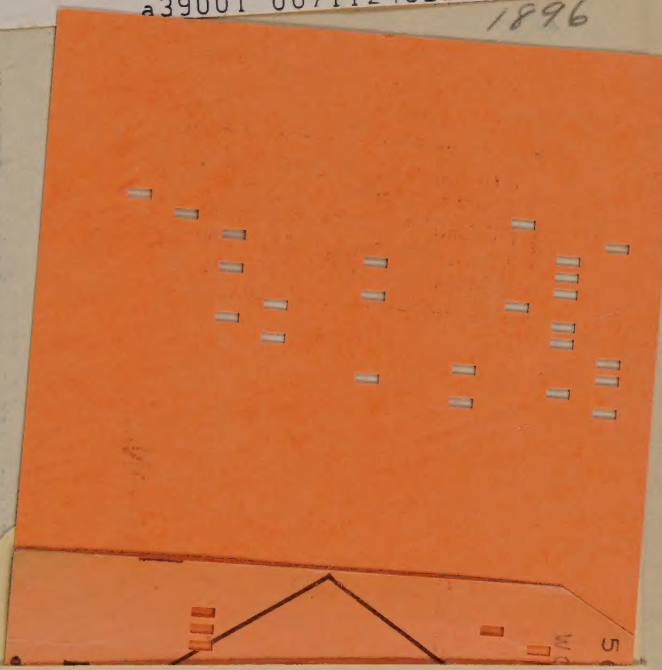
AND

H. K. LEWIS, 136, GOWER STREET, W.C.
Medical Publisher and Bookseller.

562.W89E 1896

a39001 007112462b

1896



201

S0-ELG-644